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EP 0 229 719 B1

Description

The invention relates to an on-line diagnostic system for a sealing oil system associated with a gas-cooled electric generator.

Modern electric generators such as those driven by steam turbines have the capacity to generate currents of thousands of amperes in their stator windings. Such arrangement also generates a large amount of unwanted heat due to stator and rotor winding resistance as well as windage losses. Accordingly, a cooling system must be provided in order to remove the heat resulting from the electrical and windage losses during normal operation.

One type of cooling system utilizes a flow of cooling gas, such as hydrogen, within the generator housing as well as within the rotor and stator structures to remove the produced heat.

The hydrogen cooling atmosphere must remain within the generator housing, and since the rotor shaft ends of the generator extend through the gas tight enclosure, provisions are made to prevent the escape of gas along the shaft. To this end, shaft seals, known as gland seals are provided. An auxiliary sealing oil system supplies the gland seals with oil under pressure to prevent the escape of hydrogen gas from the generator as well as to provide lubrication to the gland seals.

The sealing oil system includes sealing oil pumps, coolers, filters and a multitude of valves and monitoring devices such as gauges and alarm switches. Proper operation of the sealing oil system is maintained by an operator's visual inspection of the gauges. Audible alarms are provided for critical functions such as low sealing oil pressure or abnormal oil levels.

An abnormal gauge reading may occur at a time when the operator is not monitoring the gauges and an alarm signal may not indicate the basic problem leading up to the alarm. The present invention provides for on-line continuous monitoring of the sealing oil system and can indicate to an operator possible abnormal conditions which may be developing so that corrective action, if any, may be taken at the incipient stage of a possible malfunction.

The principal object of this invention is to provide an improved on-line diagnostic system for determining the operating status of a gas-cooled electric generator.

The invention in its broad form resides in a diagnostic apparatus for a multi-component gas-cooled electric generator seal oil system wherein the generator shaft is sealed against the escape of the cooling gas by means of spaced-apart gland seals and wherein sealing oil is supplied to the gland seals, of the type comprising: a plurality of sensors connected to sense predetermined operating parameters of said seal oil system, while on-line, and to provide respective corresponding output signals; characterized by: computer means including a rule base memory for diagnosing the on-line operating condition of said seal oil system; said rule base including rules linking a preceding evidence node with a consequent hypothesis node; a plurality of said evidence nodes constituting sensor nodes; said apparatus including means for inputting said on-line sensor signals into said sensor nodes; means for additionally inputting operator generated values into selected ones of said sensor nodes.

The preferred embodiment of the invention will be described, by way of example, with respect to the accompanying drawings in which:

Figure 1 is a simplified block diagram of a turbine-driven electric generator together with various monitoring and diagnostic systems;

Fig. 2 is a simplified layout of one type of sealing oil system;

Fig. 3 is a cross-sectional view of a typical gland seal ring used in the sealing oil system;

Figs. 4 and 5 illustrate nodal diagrams utilized to explain one type of expert system which may be utilized in the operation of the present invention;

Figs. 6A and 6B serve to illustrate typical functions which may be utilized in the expert system; and

Figs. 7 to 17 are rule base flow diagrams illustrating operation of the present invention.

Figure 1 illustrates an electric generator 10 supplied with DC excitation current from exciter 12 and driven by a prime mover such as a steam turbine 14.

The generator is of the gas-cooled variety, hydrogen being a prime example, and accordingly a hydrogen auxiliary system 16 is provided for initial charging as well as subsequent make up of hydrogen and for maintaining and monitoring the hydrogen atmosphere in accordance with predetermined dryness, pressure and purity values.

When the generator 10 is not operating, but is filled with gas, or during normal operation with shaft 18 rotating, a sealing oil system 20 provides oil under pressure to the gland seals to help keep gas from escaping from the generator and to lubricate the gland seals.

In accordance with the present invention, the operation of the sealing oil system is automatically monitored on-line. The operating condition of the sealing oil system is thus provided to an operator who can iniatate corrective action if the results of the diagnosis indicate the occurrence of one or more abnormal conditions. The diagnosis is performed by a diagnostic computer 22 which is provided with various sensor output readings from the operating system. In one embodiment, if the diagnostic computer 22 is at a location remote from the turbine generator power plant, the data gathered by the various sensors may

be first supplied to a data center 24 for subsequent transmission to diagnostic computer 22, such as described in U.S. Patent No. 4,517,468.

In addition to sensor information from the hydrogen and sealing oil systems 16 and 20, an indication of turbine generator rotational speed may be provided by means of an RPM sensor arrangement 26. Operator-entered information may be placed into the data center by means of a keyboard 28 and an interactive display 30 allows for the display of local data as well as information transmitted back by the diagnostic computer 22. A display 32 at the remote location may include both visual and hard-copy records of the results of the diagnosis.

Although the diagnosis is applicable to a variety of different sealing oil systems, it will be described by way of example with respect to a sealing oil system wherein sealing oil is supplied to two axially displaced annular grooves in the gland seal, with the inner, or hydrogen side groove and the outer, or air side groove being provided with sealing oil from two respective separate suppy systems. One such arrangement is illustrated in Fig. 2.

Fig. 2

Fig. 2 is a simplified representation of a sealing oil system of the type described, and for clarity, various isolation, throttle, pressure relief and bleed valves have been omitted from the drawing. Generator rotor 40 is illustrated together with shaft 41, the left side of which is supported in a bearing 42e (e = exciter end) and the right side of which is supported in bearing 42t (t = turbine end). The shaft is surrounded by respective gland seals 44e and 44t each of which includes a respective inner or hydrogen side circumferential groove 46e and 46t, as well as an outer or air side circumferential groove 47e and 47t.

Sealing oil is supplied to the hydrogen side grooves 46e and 46t by means of a supply pump 50h (h = hydrogen side) while the air side circumferential grooves 47e and 47t are supplied with sealing oil from pump 50a (a = air side) having a normally off backup pump 50a' in parallel therewith.

The temperature of the oil supplied by pump 50h is controlled by means of cooler 54h having external water circulating input and output lines 55h and 56h. The cool oil is then passed through a filter 58h and a check valve 234 prior to delivery to the gland seals. In a similar manner, the air side arrangement includes cooler 54a and filter 58a.

Hydrogen side sealing oil from the gland seals is discharged into respective defoaming tanks 60e and 60t, while the air side discharge is collected in a combined bearing oil and sealing oil drain 62e and 62t.

The hydrogen side sealing oil is maintained at a certain level within the defoaming tanks where most of the hydrogen entrained in the oil is removed and returned to the environment of the generator (the casing of which is not illustrated). Both defoaming tanks drain to a drain regulator 64 and then to the input side of pump 50h. The drain regulator maintains the proper amount of oil in the hydrogen side of the seal oil system.

Oil from drains 62e and 62t is combined and provided to the input side of pump 50a after passage through a loop seal and vapor extraction assembly 66 which continuously vents any hydrogen in the line to the atmosphere.

Normal sealing oil pressure is, for example, 12 psi higher than the gas presure. If the air side pump 50a should stop, or if the sealing oil pressure at the gland seals should decrease to a predetermined value, for example, 8 psi above the hydrogen pressure, a backup oil supply 70 will be put into operation to provide the necessary oil pressure for the seals.

As long as the oil pressure in the circumferental grooves exceeds the hydrogen pressure in the generator, sealing oil will flow inward rather than permitting hydrogen to escape outward. When the oil pressures at the hydrogen side/air side interface on the shaft are equal, there will be no flow of oil in the clearance space between the two circumferential grooves.

Fig. 3

For example, and with additional reference to Fig. 3, there is illustrated, in somewhat more detail, a typical gland seal 44e. The gland seal includes a gland seal ring 80 having passages which terminate in circumferential grooves 46e and 47e. For some units the gland seal ring may be comprised of two distinct side by side structures, one for the hydrogen side and the other for the air side. As indicated by arrows 82, hydrogen side sealing oil is provided through passageways to groove 46e while arrows 83 indicate the passageway flow of air side oil to groove 47e. Oil supplied by the air side of the sealing oil system flows outwardly along shaft 41 toward the bearing (not illustrated in Fig. 3). This helps to prevent release of absorbed air or moisture into the generator. Oil supplied by the hydrogen side of the system flows inwardly along the shaft toward the inside of the generator to help keep the air side sealing oil from contacting the hydrogen and to assist in preventing the escape of absorbed hydrogen to the outside atmosphere. Although there is some oil flow from each groove toward the other, the oil pressures are properly balanced and there is no interchange of oil supplies in the clearance space between the two circumferential grooves. As indicated on the Figure, the air side sealing oil drains back to the bearing drain 62e and oil from the hydrogen side of the gland seal ring drains to the defoaming tank 60e.

The surface of the seal ring adjacent the shaft 41 includes three babbits of a soft material which helps prevent damage to the shaft if sealing oil is lost. Babbit 85 is associated with the air side of the seal ring and babbit 86 is associated with the hydrogen side. Babbit 87 is shared by both sides.

Returning once again to Fig. 2, hydrogen side sealing oil supplied by pump 50h is provided to the gland seals by means of oil supply pipe 90h and the air side sealing oil from pump 50a is provided by means of oil supply pipe 90a (oil supply and return pipes are shown in heavy line). In order to balance the pressures between the two systems at the gland seals, a pressure equalizing valve 210 is provided. This valve senses the pressure of oil supplied to the hydrogen side and air side circumferential grooves 46e and 47e by means of respective sensing lines 92 and 93 and throttles oil in line 90h until the pressures are equal. A similar pressure-equalizing valve 217 is provided for equalizing the pressures at gland seal 44t by virtue of sensing line connections 94 and 95.

A float-operated drain valve 231 opens if excess oil builds up in the drain regulator 64 and releases the excess oil to the air side oil input of pump 50a. A float operated fill valve 232 opens up if the drain regulator oil level is too low, and allows make up oil from the air side pump 50a to fill the tank to the correct level.

During operation, the oil pressure at the gland seals is maintained at a certain value, for example 12 psi above the hydrogen pressure. In order to maintain this relationship in pressures, there is provided differential pressure bypass regulator valve 256 connected to sense the air side oil pressure by means of sensing line 96 and to sense the hydrogen pressure by means of sensing line 97 connected to defoaming tank 60e. In response to the sensed pressures, valve 256 is operable to bypass the output of pump 50a to maintain the established 12 psi pressure differential. As previously described, the hydrogen side oil pressure will also be at a value equivalent to 12 psi above the hydrogen pressure since the hydrogen side and air side oil pressures are equalized by operation of valves 210 and 217.

Normally closed backup differential pressure regulator valve 264 functions to allow oil from the backup supply 70 to be provided to the sealing oil system in the event of failure of pump 50a. Regulating valve 264 senses the pressure of the supplied air side oil by means of sense line 98 and the hydrogen pressure by means of sense line 99 connected to defoaming tank 60t. In a typical operation, valve 264 will open when the sealing oil pressure decreases to, for example, 8 psi above the hydrogen pressure.

The arrangement of Fig. 2 includes a plurality of sensors and indicators utilized in the on-line diagnosis of the sealing oil system. For easy reference, the sensors and indicators are set forth below in tabular form together with their particular function.

Pressure Switches

HS063	Connected across the hydrogen side sealing oil pump 50h and closes when the differential pressure thereacross decreases to 5 psi.
AS063	Connected across the air side sealing oil pump 50a and closes when the differential pressure thereacross decreases to 5 psi.
ASOB63	Connected to backup pump 50a' and activates when the backup pump is put into operation.
SOB63	Closes when the pressure from the backup oil supply 70 decreases to a certain value, for example 85 psi.
ASOH63	Connected to sensing lines 96 and 97 and closes when the oil pressure at the gland seals decreases to 5 psi above the hydrogen pressure. Closing also activates the backup pump 50a'.
DRD63	Provides indication of flow in pipe connected to drain valve 231 of drain regulator 64.

Pressure and Flow Transmitters

HSOFXD	Provides indication of differential pressure across filter 58h.
ASOFXD	Provides indication of differential pressure across filter 58a.
ASOHXD	Connected to sensing lines 96 and 97 and indicates the difference between the sealing oil and hydrogen pressures.
ASOEXD	Connected to sensing line 93 and indicates the air side oil pressure at the exciter end.
ASOTXD	Connected to sense line 95 and indicates the air side oil pressure at the turbine end.
DRFXD	Indicates flow in pipe feeding valve 232 of drain regulator 64.

Thermocouples

TC2510	Provides indication of temperature of the air side oil after passage through cooler 54a.
TC2515	Indicates temperature of input cooling water to cooler 54a.
TC2516	Indicates temperature of output water from cooler 54a.
TC2520	Provides indication of temperature of the hydrogen side oil after passage through cooler 54h.
TC2525	Indicates temperature of input cooling water to cooler 54h.
TC2526	Indicates temperature of output water from cooler 54h.

Level Switches

DTE71	Indicates high level of hydrogen side oil in defoaming tank 60e.
DTT71	Indicates high level of hydrogen side oil in defoaming tank 60t.
DRT71	Provides indication of low oil level in drain regulator 64.

DRI71	Provides indication that oil is backing up in drain regulator 64.

Gauges

ga4610	Differential pressure gauge at exciter end.
ga4630	Differential pressure gauge at turbine end.
ga4650	Hydrogen side sealing oil pressure gauge.
ga4620	Air side sealing oil pressure gauge.
ga4640	Indicates pressure at output of air side pump 50a.
olg	Oil level gauge for drain regulator 64.

Thermometers

tm520	Shows temperature of hydrogen side seal oil.
tm510	Shows temperature of air side sealing oil.

Except for the gauges and thermometers all of the above sensors provide on-line output indications to be used by the diagnostic computer 22 (Fig. 1) in the practice of the present invention.

The diagnostic computer 22 in a preferred embodiment controls the diagnostic process by implementation of an expert system computer program that uses knowledge representations and inference procedures to reach conclusions normally determined by a human expert. A common form of knowledge representation is in the form of IF....THEN rules. One such system which may be utilized in the practice of the present invention is PDS (Process Diagnosis System) described in the proceedings of the Eighth International Joint Conference on Artificial Intelligence, August 8-12, 1983, pages 158-163. Basically, in that system (as well as other expert systems) for each rule there is an antecedent or evidence (the IF portion) as well as a consequent or hypothesis (the THEN portion) which can become evidence for other rules.

Fig. 4

As depicted in Figure 4, evidence 100 is linked to the consequent hypothesis 102 by means of rule 104, with the evidence and hypothesis constituting nodes of the system. Numeral 106 represents a supporting rule of node 100, that is, a rule for which node 100 would be a hypothesis. Rule 104 is a supported rule of node 100, that is, a rule for which node 100 is evidence. Likewise, rule 104 is a supporting rule for node 102. In the system, by way of example, nodes can take the form of evidence, hypothesis, malfunctions, sensors and storage-nodes which are nodes capable of storing values input from other nodes and performing some predetermined mathematical operation on the values. In the figures, hypothesis (or evidence) nodes are octagonal, abnormal conditions are presented in a malfunction node and are illustrated as rectangles, sensor nodes are circular and storage nodes are trapezoidal.

Associated with each node is a measure of reliability, MB, that the node (hypothesis) is true, as well as a measure of error, MD, which indicates the probabilty that the hypothesis is not true. Both factors range on a scale from 0 to 1 and the difference between them, MB - MD, yields a certainty or confidence factor CF which ranges from -1 to +1, where positive numbers represent confidence that the hypothesis is true and negative numbers represent the confidence that the hypothesis is not true; numbers in the vicinity of 0 represent uncertainty.

An expert (or experts) in the field to which the diagnosis pertains establishes the various rules and relationships, which are stored in the computer's memory and utilized in the diagnostic process. The expert's confidence in the sufficiency of the rule is also utilized. This confidence, which represents the expert's opinion as to how the presence of evidence proves the hypothesis, is given a numerical representation designated as a sufficiency factor, SF, which ranges from -1 to +1, where positive values of SF denote that the presence of the evidence suggests that the hypothesis is true and negative values denote that the presence of the evidence suggests that the hypothesis is not true.

PDS additionally utilizes the expert's confidence in the necessity of the rule, which illustrates to what degree the presence of the evidence is necessary for the hypothesis to be true. This necessity is given a numeral representation designated as a necessity factor NF which ranges from -1 to +1, where positive values of NF denote that the absence of evidence suggests that the hypothesis is not true and negative values denote that the absence of the evidence suggests that the hypothesis is true.

Fig. 5

Figure 5 illustrates another common arrangement wherein a plurality of rules 110 to 112 connect evidence nodes 114 to 117 to a malfunction node 118. Element 120 represents the combining of evidence in a) a disjunctive manner, that is, if evidence 116 OR 117 is present, or b) in a conjunctive manner, that is, if evidence 116 AND 117 are present. Numeral 122 designates a NOT function and where used (although not given a numerical designation in the Figs.) indicates that the evidence to which it is linked, is not present.

Confidence leading to a consequent possible malfunction in the system being diagnosed is propagated from evidence to hypothesis in repetitive cycles, at the beginning of which the CF, MB and MD values of each node are reset to zero (except for a sensor node where the MB and accordingly the CF is assumed to be +1).

If the CF of the evidence is positive, then the rule's sufficiency is utilized to propagate confidence, whereas if the CF of the evidence is negative, the rule's necessity is utilized; if CF is zero, nothing is done.

Basically, if the evidence CF is positive and the SF is positive, then the MB of the hypothesis is increased; if the SF is negative, then the MD of the hypothesis is increased.

Conversely, if the evidence CF is negative, and the NF positive, then the MD of the hypothesis is increased, and if the NF is negative, the MB of the hypothesis is increased. By way of example, for the single rule case of Figure 4, if MB and MD are the reliability and error of the rule's hypothesis, CF the confidence in the rule's evidence, and SF and NF are the rule's sufficiency and necessity, then:

if $CF > 0$ and $SF > 0$:
$MB = CF \times SF$ (1)
MD is not changed

if $CF > 0$ and $SF < 0$:
$MD = CF \times (-SF)$ (2)
MB is not changed

if $CF < 0$ and $NF > 0$:
$MD = (-CF) \times NF$ (3)
MB is not changed
if $CF < 0$ and $NF < 0$:
$MB = CF \times NF$ (4)
MD is not changed

For the multiple rule case of Figure 5, final values are obtained by examining each rule in sequence and performing the calculations for each rule in accordance with the following, where MB_{old} and MD_{old} are the reliability and error in the rule's hypothesis (malfunction) before each calculation, CF the confidence in the rule's evidence, SF and NF are the rule's sufficiency and necessity and MB_{new} and MD_{new} are the reliability and error of the rule's hypothesis (malfunction) after each calculation:

if $CF > 0$ and $SF > 0$:
$MB_{new} = MB_{old} + (1 - MB_{old}) \times CF \times SF$ (5)
$MD_{new} = MD_{old}$

if $CF > 0$ and $SF < 0$:
$MD_{new} = MD_{old} + (1 - MD_{old}) \times CF \times (-SF)$ (6)
$MB_{new} = MB_{old}$

if $CF < 0$ and $NF > 0$:
$MD_{new} = MD_{old} + (1 - MD_{old}) \times (-CF) \times NF$ (7)
$MB_{new} = MB_{old}$

if $CF < 0$ and $NF < 0$:
$MB_{new} = MB_{old} + (1 - MB_{old}) \times CF \times NF$ (8)
$MD_{new} = MD_{old}$

For a disjunctive logical node (OR function) the highest confidence factor of all of the pieces of evidence may be utilized or the CF may be obtained by subtracting the minimum MD from the maximum MB. If the logical node is conjunctive (AND function) the minimum of all of the confidence factors may be utilized or the CF may be obtained by subtracting the maximum MD from the minimum MB. Alternatively, weighted averages may be utilized for the OR and AND functions.

The AND and OR functions are not digital (ONE or ZERO) in nature and the logic utilized is known as fuzzy logic. Accordingly, as utilized herein, fuzzy logic AND and OR functions are designated with an A and 0 respectively whereas weighted AND and OR functions are designated with a horizontal bar and the appropriate letter designation.

Thus, by utilizing the appropriate previous equations, a measure of reliability or error is calculated for a hypothesis and from these values a confidence factor in the hypothesis is calculated from the relationship CF = MB-MD.

Fig. 6 (A & B)

A rule's sufficiency (SF) or necessity (NF) may in many instances be expressed as a constant. In other instances, the sufficiency and/or necessity may be expressed as some other function which will generate a sufficiency or necessity factor of a fixed number by evaluating the function for a particular variable. A common function which may be utilized is a piece-wise linear function, two examples of which are illustrated in Figures 6A and 6B. The Y-axis in these figures represents the SF (or NF) ranging from -1 to +1 on the vertical scale. The X-axis horizontal scale represents the value of some variable such as a sensor reading or the result of some mathematical operation, by way of example. In Figure 6A, if the variable has a value between 0 and a, or is greater than f, it will generate an SF of -1 whereas if the value is between c and d, it will generate an SF of +1. Values between a and c or d and f will generate corresponding SF's between -1 and +1.

Figure 6B represents a piece-wise linear function wherein any variable value greater than b will generate an SF of +1, any variable value less than -b will generate an SF of -1 and values between -b and +b will generate a corresponding SF between -1 and +1.

Another type of useful rule is a reading-transform rule which, when carried out, applies a transform function to the value found in the rule's evidence node. If the evidence node is a sensor, the value is a sensor reading, with appropriate conversion, scaling, etc., performed by the transform if needed.

Figures 7-17 are nodal diagrams or rule base flow charts illustrating the diagnostic process of the present invention performed by diagnostic computer 22 for arriving at various sealing oil system abnormal conditions based upon sensor readings, and implemented in accordance with the expert system previously described.

With respect to Figs. 7-17, some of the hypotheses used in one figure may emanate from another figure and to provide some guide to the origin of an hypothesis, reference may be made to Appendix A. This Appendix sets forth in tabular form the hypothesis designation in numerical order, together with a brief explanation and the figure number where the hypothesis is first generated.

The diagnosis presented in Figs. 7-17 relates to the sealing oil system described by way of example in Fig. 2 and accordingly, additional reference should be made to Fig. 2.

FIG. 7 (A & B)

Figure 7 illustrates some possible abnormal conditions which may be diagnosed and which relate to the hydrogen side oil flow. One such condition is indicated at node m400 designating to an operator a loss of pump action on the hydrogen side sealing oil system. Normally this is indicated by activation of the pressure switch HSO63 connected across pump 50h. The output indication provided by HSO63 is also used in the present arrangement but additional supportive evidence is included leading up to the particular condition. The on-line sensor readings are automatically scanned and placed into sensor nodes of the expert system. Two such sensor nodes are illustrated in Figure 7 and are respectively designated by their sensor names HSO63 and HSOFXD. Rule r400 relates the sensor condition of HSO63 into a belief that the hydrogen side sealing oil pump 50h is off (or providing insufficient pressure), node h400. Normally in the absence of any sensor abnormality, confidence in the hydrogen side pump being off may be propagated unaltered and used in the determination of loss of pump action, node m400. In the presence of a sensor abnormality however the confidence must be reduced.

Basically, the modification of the confidence is accomplished by a parametric alteration rule which is operable to change the sufficiency function and/or necessity function of another rule. Accordingly, an analysis is made regarding the operability of switch HSO63. The analysis may result in a determination of a faulty HSO63 switch (or its associated circuitry), node m401 at the lower right portion of Figure 7A. If indeed the switch is faulty, a parametric alteration rule pr4 is generated to alter the sufficiency of rule r401 linking hypothesis h400 with hypothesis h409 indicating a validated conclusion regarding the hydrogen side pump being off. That is, in the absence of a faulty HSO63 switch, the confidence in the hydrogen side pump being off is propagated unaltered to node m400, whereas if there is a faulty switch, the propagated confidence would be proportionately lower.

Additional evidence leading to the conclusion of the loss of pump action includes an hypothesis h499 at the upper left hand corner of Fig. 7A and statng that the cooler water differential temperature is approximately zero. In other words, if thermocouples TC2525 and TC2526 transmit substantially identical temperatures of the input and output cooling water to cooler 54h, this indicates that hot oil is not being pumped since, if hot oil were being circulated by pump 50h, the cooling water would remove the heat and experience a rise in temperature. This condition is linked to node m400 by means of rule r4005.

Sensor readings from the hydrogen system 16 (Figure 1) may also be utilized in the diagnosis of the sealing oil system 20. Hypotheses generated in the hydrogen system and utilized in the sealing oil system diagnosis are shown in the Figures in dotted form, one of which is h209. One such hhpothesis is that the hydrogen purity is low, a condition which may be caused by lack of pumping action allowing air side oil into the defoaming tanks resulting in air entering the generator atmosphere and degrading the hydrogen purity thereof.

Although these two latter conditions, low hydrogen purity and cooler water differential temperature being zero contribute additional confidence in the loss of pump action, their contribution would not be as great as the validated conclusion that the hydrogen side pump was off transmitted from h409. Accordingly, the sufficiency factors of rules r4005 and r4004 linking nodes h499 and h209 to node m400 would not be as great as the sufficiency factor for rule r4003 linking node h409.

Another observation lending more credence to the loss of pump action conclusion may be derived from sensor HSOFXD across filter 58h. If the pump s not working there is no oil flow and accordingly there would be no pressure drop across the filter. Rule r405 converts the sensor reading into a confidence that the differential pressure across the filter is nearly zero, node h513. This ΔP determination may be validated by checking to see if sensor HSOFXD generates a parametric alteration rule to modify the sufficiency and/or necessity of rule r4001 linking h513 with the conclusion depicted at m400.

Rule r408 at the lower left portion of Figure 7A establishes that a difference exists between certain derived indications, and utilizes a plurality of logic functions 300 to 302. Basically, rule r408 may be traced back via AND functions 300 and 301 to hypotheses h400, h513 and h499. As depicted at AND 300, if the hydrogen side pump is indicated as being off, the differential pressure is not zero as it should be for such a condition and the cooler water differential temperature is not zero as it should be for such a condition, then rule r408 establishes that a disagreement exists, node h518. Conversely, r408 also applies if, as depicted at AND 301, the cooler water differential pressure is zero and the differential pressure across the filter is zero but the hydrogen side pump is indicated as not being off. In accordance with the present invention if this disagreement does exist then off-line readings are additionally used in the diagnostic process, such off-line procedures being indicated in the Figures by means of the dot-dash lines.

With the occurrence of this disagreement indication, a message is provided to the operator, as indicated by procedure PI to read gauges ga4610, ga4630 and ga4650 and to enter their values into the system. This is accomplished with the provision of keyboard 28. Once inputted, the values read are placed into the respective sensor nodes ga4610, ga4630 and ga4650 illustrated in Figure 7B. Storage node stn419 receives the gauge ga4650 reading via a reading transform rt432 and receives an indication of hydrogen pressure by means of reading transform rt433 from a sensor HYDXD located in the hydrogen system. The storage node operates to take the difference in the two readings and, via rule r409 transforms this difference into a confidence level that the oil pressure is approximately equal to the gas pressure, node h403. Since check valve 234 is downstream of gauge 4650, if pump 50h is off, the pressure indicated by this gauge would be the hydrogen gas pressure existing in drain regulator 64.

The other two gauge readings in sensor nodes ga4610 and ga4630 are utilized to determine if the air side oil pressure is high at the exciter end as well as at the turbine end. These two differential gauges should normally read approximately zero. If the hydrogen side pump 50h is off, then reduced oil pressure exists in the hydrogen side oil delivery pipe 90h and the air side pump 50a supplies all of the sealing oil to both the air side and hydrogen side grooves resulting in a significant differential pressure due to the higher air side oil pressure. The determination of high air side oil pressure is accomplished by use of rule r402 which may use a piece-wise linear mapping of the particular reading into a determination of high air side pressure at node h401 associated with the exciter end. Similarly, rule r403 links the sensor reading of ga4630 with hypothesis h402 indicative of a high air side pressure at the turbine end. These two conditions are utilized by rule r512 including AND function 304 to determine at node h460 that high air pressure exists at both the exciter and turbine ends. The latter condition and the condition of the oil pressure being approximately equal to the gas pressure are both linked to the loss of pump acton node m400 by

means of rules r4008 and r406 respectively and both have relatively high sufficiency factors in determining the abnormal condition at node m400.

The off-line readings are also used to assist in the determination that a faulty HSO63 switch exists as previously set forth at node m401. For example, rule r4122 utilizes AND function 306 to determine that the hydrogen side pump is off according to off-line sensors, node h567. This conclusion is reached if, according to node h460, both the exciter and turbine ends have high air pressure, and the oil pressure is approximately equal to the gas pressure, node h403.

If, according to off-line sensors, the pump is off and it is not off according to switch HSO63 (AND 308), or, if the pump is off according to HSO63 (OR 309) but not off according to the off-line sensors (AND 310) then rule r4123 uses the conclusions of hypotheses h400 and h567 to determine the probability that a faulty HSO63 switch exists.

Two other pieces of evidence are utilized in determining whether switch HS063 is faulty, one of which is propagated by rule r4009 and the other by rule r4010. Rule r4009 utilizes a weighted AND function 312 which combines the evidence that the pump is off according to HSO63 coupled with the data that the cooler water temperature differential is not zero, the hydrogen purity is not low and the differential pressure across the filter is not zero. If these three latter conditions exist then the pump should not be indicated as being off and accordingly the switch is probably bad.

Rule r4010 utilizes weighted AND function 313 to reverse the consideration of weighted AND 312.

The off-line sensor readings of gauges ga4610 and ga4630 may be used to diagnose other potential problems. For example, if there is high air side pressure at the exciter end but not at the turbine end, rule r4016 n Figure 7B uses AND function 316 to determine that a problem is likely to exist in the exciter and as depicted at node h520. If there is a problem in the exciter end and if the drain valve 321 is opened, node h454, then rule r4018 uses AND function 318 to arrive at the conclusion, node m477, that there is ring wear on the exciter end of the hydrogen side sealing oil ring. This conclusion is reached because, with a bad ring, more oil than normal will be drained into the drain regulator resulting in float operated drain valve 231 being opened. If however, drain valve 231 is not open then it is likely that differential pressure valve 210 is in a closed condition, node m443, using rule r4019 and AND function 319.

FIG. 8 (A & B)

Figures 7A and 7B illustrate the diagnostic process used to determine possible abnormal conditons relative to the hydrogen side oil flow. Figures 8A and 8B illustrate the diagnostic process used to determine possible abnormal conditions relative to the air side oil flow. The on-line condition of pressure switch ASO63 connected across air side pump 58a is input to sensor node ASO63 in Figure 8A and rule r410 derives the confidence level that the air side pump is off, node h569. Rule r4126 may have its sufficiency and necessity changed by parametric alteration rules pr434 and pr433 to conclude, node h404, that the air side pump is indeed off.

This confidence level is linked by rule r411 to the conclusion, node m403, that there is a loss of pumping action on the air side sealing oil system. This conclusion is reached by knowing that the air side sealing oil pump will deliver oil at a pressure which is approximately 12 psi above the hydrogen gas pressure. If pumping action should stop, the backup oil supply 70 will come on line. However, the oil delivered by the backup supply is at a pressure lower than that normally supplied by the air side pump. Therefore a differential pressure of 8 psi between the air side oil pressure and the hydrogen pressure, as opposed to the normal 12 psi difference, indicates loss of air side pumping action.

The two sensors for determining air side oil pressure are ASOEXD at the exciter end and ASOTXD at the turbine end. A determination is made (Fig. 12) as to whether or not these values agree and the results are utilized in the diagnostic procedure of Figure 8A at node h474. In addition, the maximum pressure indicated by these two sensors is utilized and compared with the hydrogen pressure to see if the difference, indicated at node h512 is approximately 8 psi.

In Figure 8A, rule r4023 utilizes AND function 320 to check if the sensors agree, h474, and if the differential pressure is 8 psi, h512. The conclusion that the differential pressure is 8 psi but there is no sensor reading agreement, node h506, is output as rule 4026 to the loss of pumping action node, m403. If the 8 psi differential exists and there is agreement between the two sensors, AND 322 outputs the two confidence levels as a rule, r4024 to node h522 which in turn outputs the conclusion r4027 to node m403 thereby increasing the confidence level in the conclusion that there is a loss of pumping action, m403.

If the air side pump is off and the conclusion of node h506 is not present or if it is present and the air side pump is on, then rule r4025 uses this information to conclude, using AND and OR functions 322 to 324, that a disagreement exists, node h523. This disagreement prompts a procedure P2 wherein the operator reads gauges ga4620 and ga4640 and enters their present values via the keyboard. These values are shown in the diagnostic process as sensor nodes ga4620 and ga4640 seen in Fig. 8B.

Rules r412 and r413 use piece-wise linear functions to map the reading of ga4640 into a confidence level that the pressure is either low or that the pressure is normal, shown respectively at nodes h405 and h406. Normal pump pressure may, for example, be in the range of 130 to 150 psi whereas a low pres-

sure may be any pressure below 120 psi. Pressures outside of the stated values would generate sufficiency factors other than 1 in accordance with the piece-wise linear functions used.

Since there is normally a pressure drop across the cooler and filter, gauge ga4620 will indicate a lower pressure such that the low pressure indication at node h407 may be indicative of a pressure below 100 psi, as determined by rule r416.

The low pressure indication at node h405 is used, by rule r4028, with another evidence, to conclude there is a loss of pumping action, node m403. The low pressure indication is also used by rule r4140 with other evidence to indicate a failure of the backup oil supply, node m405. Node m405 also uses the low pressure indication of node h407 linked by rule r4139.

Another indication of the failure of the backup supply is the presence of low turbine backup pressure, propagated by rule r4138, indicated at node h410 and determined utilizing rule r473.

Evidence of backup source failure may also be provided by an indication that the differential pressure is below what it should be, that is, 8 psi. Rule r4124 uses AND function 326 to examine the evidence presented by hypotheses h550e and h550t, stating that the air side exciter end and air side turbine end sensor values minus the hydrogen pressure result in a differential pressure of less than 8 psi. If these two conditions exist, then node h568 concludes that the differential pressure is less than 8 psi and this conclusion is linked to node m405 by rule r417.

The conclusion of h568 is also used in rule r4125 to determine possible backup source failure. Rule r4125 includes an AND function 328 as well an OR function 329 such that if the turbine end differential pressure indicates a negative rate of change (h509) or if the exciter end differential pressure indicates a negative rate of change (h480) that is, the differential pressure is decreasing, then a backup source failure is indicated if the differential pressure is less than 8 psi.

As previously described, the air side pump off condition of node h569 is validated at node h404 in accordance with parametric alteration rules pr433 and pr434. The propagation of the confidence level that the air side pump is off may be terminated if the pressure switch ASO63 is in fact faulty, with this determination being made at node m404 in the lower portion of Fig. 8B. To arrive at the conclusion of a faulty switch, rule r415 takes into account various pieces of evidence utilizing AND functions 331 to 333 and OR function 334.

For example, using AND function 331, a faulty switch may be indicated if the air side-to-hydrogen pressure differential is approximately 8 psi, the exciter end and turbine end pressure sensors agree and the air side pump is not off. AND function 332, in determining the probability of a faulty switch, receives input of low gauge pressure, node h405, indication that the pump is not off, node h569, and an indication that the backup pump is not on. This latter determination is made at node h408 using the backup pump pressure switch ASOB63 indication together with rule r474.

AND function 333, in determination of the probability of a faulty switch, receives inputs such as the backup pump and the air side pump both being off coupled with the gauge pressure being normal, node h406. For such inputs, if both pumps are off, then the pressure cannot be normal and accordingly a faulty AS063 switch is assumed.

FIG. 9 (A & B)

Figures 9A and 9B depict abnormal conditions associated with the drain regulator 64. Sensor node DRI71 contains the condition of this switch, linked to the hypothesis via rule r424 that, if the switch is activated, the drain regulator tank level is backing up. If the generator unit is off-line, rule r485 uses the evidence of the tank level backing up to conclused that oil is about to enter the generator unit through the sealing oil ring, node m435. This conclusion is supported by evidence from an off-line indication linked to the hypothesis at node h464 by rule r4031 that the oil level gauge olg indicates a high level condition.

Figure 9B illustrates rules r530 and r531 which convert the switch indication of sensor node DRD63 and flow indication of sensor node DRFXD into respective confidence levels that the drain valve 231 is open, node h454, and that the feed valve 232 is open, node h453.

By means of AND function 336, rule r526 receives inputs of the valve conditions and if the drain valve 231 is indicated as open, the feed valve 232 is indicated as closed, and the tank level is indicated as high, node h455, then a suspicious condition exists, node h468, since the oil should be draining from the tank and therefore not backing up.

Similarly a suspicious condition is indicated by rule r527 using AND function 337 and receiving the inputs that the feed valve 232 is opened, the drain valve 231 is closed and the tank level is low.

The presence of a suspicious condition, node h468, will instruct the operator to use procedure P3 to read gauge olg and enter the value of 1 if it indicates a low condition, a -1 if a high condition is indicated, or a zero if the condition is not certain. Rule r497 uses a piece-wise linear function to then convert the reading to a confidence level that the olg is high. If a 1 were entered at node olg, the confidence in a high olg at node h464 would be negative, indicating that the hypothesis (high level) is not true.

Nodes h453 and h454 in Fig. 9B indicate the open condition of the feed valve 232 and drain valve 231 respectively. These conditions may be utilized to determine the combinations of conditions in which these valves may be open or closed. For example, rule r487 uses AND function 340 receiving the inputs that

the feed valve 232 is open and the drain valve 231 is closed to conclude that the feed valve is open and the drain valve is closed node h465. Similar logic may be used to determine that the feed valve is closed while the drain valve is opened. Rule r528 uses AND function 341 to conclude that both valves are open, node h469 (since there is no negation function at AND 341), leading to an abnormal condition indication at node m453, linked by rule r529, that the drain and feed valves on the drain regulator tank are opened simultaneously, a condition that should not be occurring.

The simultaneous condition of the valves as set forth at nodes h465 and h469 are used, with other evidence, to determine, further abnormal operating conditions. For example, in Fig. 9A rule r489 uses AND function 344 receiving as inputs backing up of the tank level, node h455, and an indication that the feed valve is open while the drain valve is closed, node h465 to determine that the drain regulator tank level is high, node m442.

If the drain tank level is backing up, the level is not high due to the feed valve being stuck open, and if both valves are not open, then a conclusion is drawn that the tank is backing up due to some obstruction in the drain line, rule r491 linked with rule r4033.

FIG. 10

The diagnostic process illustrated in Figure 10 uses the status of the exciter and turbine end defoaming tank sensors DTE71 and DTT71 to determine abnormal conditions occurring in the defoaming tanks 60e and/or 60t.

With respect to the exciter end diagnosis, rule r535 converts the contact input into a confidence level that the exciter end defoaming tank level is high, node h472. If the hydrogen side oil is also hot, node h484, then rule r538 uses AND function 350 to conclude that the oil level in the defoaming tank 60e is high and contains hot oil, node h526. The same conclusion is reached at node h527 in the analysis of the turbine end defoaming tank using the sensor input of DTT71, rule r422, hypothesis h414 and rule r533.

The determination at node h570 that both the exciter end and turbine end defoaming tank levels are high is made using rule r4127 in conjunction with AND function 352.

With this information, various conclusions may be drawn about possible abnormal conditions of the exciter and turbine end defoaming tanks. For example, if the hydrogen side oil is hot it will be less viscous and will flow more readily. If the level is high in both the exciter and turbine end defoaming tanks and if the oil is hot in both of these tanks, then rule r4045 uses AND function 354 to determine that the high level on both defoaming tanks is due to the hot hydrogen side seal oil, node m482.

With respect to the exciter end defoaming tank, rule r4044 uses AND function 355 receiving inputs that the level is high and the oil is hot in the exciter end defoaming tank and that there is not a high level in both defoaming tanks, node m482, to conclude that there is a high level on the exciter end (only) defoaming tank due to hot oil, node m456.

The high level could also be due to some obstruction in the drain line which goes to the drain regulator, node m457. It is determined by rule r539 using AND function 356 receiving the inputs that the level is high but not due to hot oil, node h526, that both sides are not high, node h570 and that the level is high in the exciter end defoaming tank node h472.

The identical conclusions are presented for the turbine end defoaming tank at nodes m409 and m454 utilizing rules r4046 and r532 with their respective AND functions 357 and 358.

FIG 11

Figure 11 illustrates the possible outputs of sensor ASOHXD which provides to its counterpart sensor nodes the value of the differential pressure between the hydrogen and air side oil pressures. Under normal operating conditions the oil pressure may be around 87 psi and the hydrogen gas pressure around 75 psi resulting in a differential pressure $\Delta P = 12$ psi. All hypotheses shown at the sensor nodes are determined by a piece-wise linear function dependent upon the actual pressures designed for the particular sealing oil system. Storage node stn402 linked to the sensor reading by reading transform rt404 calculates the rate of change of the differential pressure and determines whether the difference between the two pressures is getting smaller.

An abnormal condition which has an exceptionally high priority is that of very low sealing oil pressure, node m483. Rule r4052 uses the combining logic of functions 360 to 362 to determine if the differential pressure is below 5 psi. That is, if the oil pressure is not at least 5 psi above the hydrogen gas pressure then an emergency situation may exist. The logic functions associated with rule r4052 determine that if the differential pressure is approximately equal to 5 psi or less and if the backup pump is on or the pressure switch ASOH63 has activated, indicating a pressure less than 5 psi, rule r467 and hypothesis h431, then low sealing oil pressure is present, node m483.

Another abnormal condition is indicated at node m484 relating to the malfunction of differential pressure bypass regulator valve 256 which may have failed or which may have an incorrect setting. Rule r4053 uses AND function 364 to determine that the differential pressure as measured by sensor ASOHXD is high coupled with the fact that the turbine backup pressure is not low and that the air side pump is not off. That is, if the air side pump 50a is correctly operating, then a differential pressure higher than

normal suggests trouble with valve 256, the setting of which should maintain the desired 12 psi pressure differential during normal operation.

The abnormal condition defined at node m485 relates to the malfunction or incorrect setting of backup differential pressure regulator valve 264. If the air side pump is down, the oil is being supplied by the backup oil supply 70 to maintain a differential pressure with respect to the hydrogen pressure of 8 psi. If the differential pressure is high and the air side pump is off, then the pressure regulation provided by valve 264 is incorrect since the differential pressure should not be high but should be 8 psi. Rule r4055 uses AND function 370 to reach this conclusion, node m485. This conclusion may be reached using other evidence from inputs to logic nodes 366 to 368. The differential pressure may be measured directly by sensor ASOHXD and/or indirectly by the individual sensors ASOEXD and ASOTXD compared with the actual hydrogen pressure. If the differential pressure as measured by any one of these three methods is not decreasing, that is, the system is stabilized, and if the air side pump is off, node h404, then trouble with valve 264 is indicated if the differential pressure is less than 8 psi.

FIG. 12

The diagnostic procedure illustrated in Figure 12 uses individual sensor readings to establish differential pressure ranges. Sensor nodes ASOEXD and ASOTXD receve pressure values from their respective sensors indicative of the gland seal air side oil pressure at the exciter end and at the turbine end respectively. The hydrogen pressure stored in node HYDXD is subtracted from the turbine and exciter end pressure values in respective storage nodes stn405 and stn406 linked by respective reading transform rules rt409 to rt412.

Several of the differential pressures with respect to the exciter end are set forth below together with their associated hypothesis and rule, each of which would incorporate a different piece-wise linear function:

Differential Pressure	Hypothesis	Rule
Between 8 & 12 psi	h457	r547
Approximately 8 psi	h535	r4060
Between 5 & 8 psi	h450	r548
Approximately 5 psi	h479	r546
Between 0 & 5 psi	h536	r4061
Less than 0 psi	h478	r545

In addition, reading transform rt413 links the difference, in storage node stn406, to storage node stn407 in which the change in differential pressure with respect to time is derived and rule r540 determines whether this change is negative, node h480.

Several differential pressure values with respect to the turbine end are set forth below.

Differential Pressure	Hypothesis	Rule
Approximately 12 psi	h540	r4065
Between 8 & 12 psi	h541	r4066
Approximately 8 psi	h542	r4067
Between 5 & 8 psi	h543	r4068

In addition, the confidence level in a negative rate of change is established at node h509 using rule r4074, storage node stn416 and reading transform rt431.

Figure 12 additionally illustrates other information which may be derived from the sensor readings. For example, storage node stn403 linked to sensor node ASOEXD by reading transform rt405 and to ASOTXD by reading transform rt406 may be used to determine the higher of the two sensor readings. The higher valued reading is linked by reading transform rt425 to storage node stn415 which also receives the hydrogen pressure via reading transform rt426 and computes the difference. By means of a piece-wise linear function associated with rule r4057, a determination is made as to whether or not the maximum differential pressure is approximately 8 psi, node h512.

Reading transforms rt407 and rt408 also place the sensor values into storage node stn404 in which the difference between them is computed and, by means of a piece-wse linear function associated with rule r541, whether this difference is significant, node h474.

FIG. 13

The differential pressure values derived in Figure 12 may be used to diagnose various abnormal conditions. For example, a coonclusion that the air side sealing oil ring on the exciter end (only) gland seal is worn may be reached from coidering the inputs that a significant difference exists between the ASOEXD and ASOTXD readings, node h474; the air side pump is on, negated node h404; the differential pressure is less than 12 psi at the exciter end; and the differential pressure at the turbine end is approximately 12 psi, node h540.

A conclusion that there is a worn sealing oil ring on the exciter end may also be reached from rule r554 using AND function 382 receiving as inpuuts the signals that the differential pressure is less than 8 psi; the air side pump is off, h404; a significant difference between the ssensor readings exists, h474; the backup pump is not on, negated node h408; and the turbine end differential pressure is approximately 8 psi node h542. Although the determination of a worn sealing oil ring using rule 554 is similar to that using rule r557, the rule r554 is applied to operation of the system wherein the backup oil supply 70 is activated, during which time differential pressure should be 8 psi.

An increased oil flow increases confidence that there is a worn sealing oil ring and manifests itself by a higher differential pressure appearing across the air side filter 58a, node h462.

By using the pressure sensor on the turbine end, and the differential pressures derived with that sensor, the diagnostic process illustrated in Figure 13 can be equally applied to the determination of a worn air side sealing oil ring on the turbine end. Hypothesis h550t utilized in Fig. 8A and establishing a differential pressure less than 8 psi at the turbine end would be derived exactly as in h550e for the exciter end, using pressure ranges derived with sensor ASOTXD instead of ASOEXD.

FIG. 14

Figure 14 illustrates the diagnostic process for determination of the general condition of excessive ring wear and not the specific condition of air side ring wear on the exciter end or turbine end. The determination of hydrogen side ring wear could be made if hydrogen side pressure sensors were provided. However, the arrangement of Figure 2 only includes air side sensors ASOEXD and ASOTXD. Accordingly, the determination of general sealing oil ring wear, as set forth in Figure 14, is based upon evidence other than would be provided by hydrogen side sensor readings.

If the hydrogen side portion of the sealing oil ring is worn, there will be excessive oil flow due to the greater gap between the seal and the shaft. When this occurs, oil may work itself into the generator housing along the shaft or the defoaming tank may back up to a point where oil enters the generator. Accordingly, one of the prime considerations for sealing oil ring wear is the possibility of oil entering the generator. The generator includes oil leak detectors as part of the hydrogen purity system and if there is an oil leak detected at the turbine end or if there is oil in the generator's lead box, indicating an oil leak at the exciter end, then rule r4000 uses OR function 386 to conclude that there is oil entry, node h504.

With respect to the problem of worn sealing oil rings, however, oil entry may be due to the oil being excessively hot, in which case the gland seal ring may expand increasing the gap between it and the shaft and resulting in oil entry. Accordingly, rule r599 uses AND function 387 to conclude that there is oil entry, at node h505, only after considering the oil temperature, node h428.

The purpose of the dual oil system, a hydrogen side supply and an air side supply, is to prevent the hydrogen side oil from becoming contaminated with water or air. If there is excessive ring wear, the air side oil may mix with the hydrogen side oil and contaminate it such that water and air which normally may be present in the air side oil diffuse out of the hydrogen side oil and mix with the general atmosphere within the generator increasing its humidity and decreasing its purity, node h503.

Similarly, the determination of low purity, node h502, is reached using AND function 392 receiving inputs that the hydrogen purity is low; the hydrogen side pump is not off; and the oil is not hot.

The confidence in excessive ring wear at node m418 is modified by rule r4146 if the differential pressure is not within the proper operating range. The output of AND function 395 requires both the exciter end and turbine end differential pressures to be between 8 and 12 psi derived from the individual exciter end and turbine end pressure sensors ASOEXD and ASOTXD respectively. Alternatively, using OR function 394 this same pressure differential range may be established by the single sensor HSOHXD.

A final determination of an abnormal condition is provided by rule r4145 having as input a high differential pressure across the hydrogen side filter, indicative of a greater oil flow due to worn rings.

FIG. 15 (A & B)

Figures 15A and 15B illustrate diagnosis of possible abnormal conditions with respect to the hydrogen side oil temperature. Identical considerations can be given to the air side oil temperature using the respective appropriate sensors.

The hydrogen side oil temperature is derived from thermocouple TC2520 at the output of cooler 54h. Using rule r430, the reading of TC2520 is examined and if it is above or below predetermined known amounts, the determination is made, node h446, that the thermocouple reading is out of range leading to a defective thermocouple conclusion, node m413.

If a defective thermocouple is initially determined, a procedure P4 may be indicated to the operator whereby thermometer tm520 is to be read and the temperature value entered into the diagnostic system at sensor nodes tm520. This same procedure is also initiated if a significant difference exists between the outputs of the hydrogen side and air side thermocouples TC2520 and TC2510. Reading transforms rt417 and rt418 provide the thermocouple values to storage node stn409 which checks to deterine if a significant difference exists between the two values, node h490. The existence of this significant difference requires an operator to read the thermometer values and enter the values into the system.

The diagnostic process examines the output of TC2520 to see if the oil is cold or hot. This is respectively accomplished with rule r431 and node h416 for the cold determination, and rule r432 and node h420 for the hot determination.

If there is an indication of a defective thermocouple at node m413, parametric alteration rule pr402 changes the sufficiency of rules r434 and r436 leading to a first validation of cold and hot oil in nodes h418 and h419 respectively. If the confidence in the defective thermocouple determination is negative, the sufficiency of rules r434 and 436 will remain unchanged. A parametric alteration rule pr410 is also used to change the necessity function of rules r435 and 437 leading to respective second validations of the cold and hot state of the oil at nodes h483 and h484 respectively.

Other input signals may be used to determine not only the cold or hot oil states but also the presence of a defective thermocouple. For example, at the upper left portion of Figure 15A, the thermometer reading at node tm520 is related to a determination of cold oil at node h417 by rule r433. If the oil is cold as determined by the thermometer reading, a parametric alteration rule pr403 will increase the sufficiency of rule r435 tending to further validate the cold reading provided by the thermocouple TC2520. Rule r516 the cold oil signal from node h417 contributes some degree of confidence to the second validation of cold oil at node h483. If a determination of a defective thermocouple is made, parametric alteration rules pr417 and pr418 will increase the sufficiency and necessity of rule r516 so that the cold oil determination is primarily derived from the thermometer reading, since the thermometer is less likely to be defective. If the indication is that the thermocouple is not defective, the sufficiency and necessity of rule r516 will be decreased so that the cold oil determination is made usng the thermocouple reading. Once the validation of cold oil has been made, rule r560 links this to the abnormal condition indicated at m411 that cold oil exists in the hydrogen side, with the likelihood that it is due to high water flow through the hydrogen side cooler.

If it has been determined, at node h484 that the oil is hot, rule r561 uses AND function 400 receiving the inputs that the oil is hot and that the water flow to the cooler has been increased, node h563, to conclude that hot oil exists, but the cause is unknown. This observation at node m412 is also operative to trigger procedure P4 if not already done.

The hypothesis of hot oil at node h484 uses other inputs in arriving at this conclusion. For example, the operator entered reading of thermometer tm520 is mapped into a confidence level, at node h560, that the oil is hot, by rule r438. If the oil is hot, there is an increased flow thus causing a higher differential pressure across the hydrogen side filter 58h and rule r4099 uses this input to increase the confidence level of the existence of hot oil at node h560. Rule r517 also provides input to node h484 that the oil is hot in a manner similar to the cold oil determination.

The hypothesis of node h441 in the lower left-hand portion of Fig. 15B is that a disagreement exists between the on-line sensor reading of the thermocouple TC2520 and the visual reading of the thermometer tm520. This hypothesis is reached by rule r440 using OR function 402 and AND functions 403 and 404. The rule examines the thermocouple and thermometer readings and if the thermocouple indicates that the temperature is hot while the thermometer indicates that it is not hot, or conversely, if the thermometer indicates that the temperature is hot while the thermocouple indicates that it is not hot, then a disagreement exists and procedure P5 is initiated requiring the operator to feel the oil pipe coming from the cooler and if it feels hot, to enter a 1 by operation of the keyboard and if it is not hot, to enter a -1, with the results appearing at tactile sensor node ts.

The reading ts can be used as a check on the thermocouple and thermometer. This third level backup uses rule r439 to map the confidence level in a hot oil condition into a conclusion of hot oil at node h442. If the oil in fact does feel hot, rule r443 linking this node with the validated hot oil conclusion at node h484 adds some evdence to this validation.

Rule r442 at the extreme right of Figure 15B uses the thermocouple thermometer and tactile readings to determine whether or not the thermometer is actually defective. This determination is made using functions 406 to 408 which receive as input both the cold side and hot side conditions. If the thermocouple in-

dicates that the oil is cold and the thermometer indicates that the oil is hot while the tactile sensor indicates that the oil is not hot, then it is likely that the thermometer is in error as depicted at node m445. Similarly, if the thermocouple indicates that the oil is hot and the tactile sensor indication is that the oil is hot while the thermometer indicates that the oil is not hot, a defective thermometer is indicated.

With the conclusion that the thermometer is defective, other rules involving a thermometer reading may now be modified to decrease their contribution in the determination of a defective thermocouple at node m413. For example, using reading transforms rt400 and rt401, the difference between the thermometer reading and thermocouple reading is established at storage node stn400. Rule r444 examines the difference and if it is greater than for example 5 to 8 degrees, a high confidence in the difference is established at node h448. Since the probability of failure of a thermocouple is greater than that of a thermometer, rule r523 increases the confidence of a defective thermocouple at node m413. If, however, it has been determined at node m445 that the thermometer is defective, a parametric alteration rule pr419 is operable to change the sufficiency of rule r523 to terminate the confidence in the difference so that it has no effect on the defective thermocouple determination.

As a further example, rules r4097 and r441 in Fig. 15B utilize AND functions 410 and 411 to examine the three indications of hot oil: the thermocouple reading, the thermometer reading and the tactile reading. If the thermocouple disagrees with the other two, then confidence in a defective thermocouple at node m413 is increased. If, however, the thermometer is defective, the necessity of these rules may be increased by a parametric alteration rule pr411 to reduce the belief in a defective thermocouple.

FIG. 16 (A & B)

Figures 16A and 16B illustrate possible abnormal conditions which may be associated with the cooler 54h, and particularly with the cooling water supply in pipes 55h and 56h. Again, the process is identical with respect to the air side cooler 54a with water pipes 55a and 56a using the respective sensors associated with these components.

Thermocouple readings are input to sensor nodes TC2525 and TC2526 and are indicative of the cooler inlet and outlet water temperatures respectively. Rule r588 converts the thermocouple reading of TC2525 into a confidence level, node h494, that the inlet water is cold while rule r587 converts the reading into a confidence level node h493, that the inlet water is hot.

Reading transforms rt421 and rt422 provide the readings to storage node stn410 which determines the difference between the two temperature readings and rule r4150 (Fig. 16B) converts the difference readings into a confidence level that the differential temperature is low, node h576. Rules r586 and r583 convert the results of the subtraction process into respective confidence levels that the differential temperature is high, node h492, and that the differential temperature is approximately zero, node h499.

At storage node stn413, linked to the difference value by reading transform rt423, the rate of change of the differential temperature is determined. Rules r585 and r584 then convert the rate of change function into a confidence level that the rate is fast, node h501, or conversely, that the rate is slow, node h500.

From these established confidence levels, various conclusions may be reached, the simplest being at node m472 linked to node h493 by rule 590 and stating that there is a high inlet water temperature. Rule r595, uses AND function 420 receiving as inputs the cold inlet water determination of node h494 and a cold hydrogen side oil determination established by thermocouple TC 2520 to conclude that the hydrogen side sealing oil temperature is cold, node m474. However, it is now established that the sealing oil temperature is due to the cold inlet water to the cooler.

Similarly, rule r594 uses AND function 422 to conclude that the hydrogen side sealing oil is hot due to hot inlet cooling water, node m471. Once the determination has been made that the inlet cooling water is hot, it is unnecessary to display the confidence level of node m472 and accordingly, parametric alteration rule pr424 eliminates the sufficiency of rule r590 to terminate propagation of the confidence level.

If the hydrogen side oil is hot, and the difference between the inlet and outlet water temperatures is increasing at a fast rate, then rule 593 uses AND function 424 to convert this into a confidence level that there must be a restriction in the water flow circuit, node m470. This is particularly true if the differential temperature is high, linked to the confidence level by rule r572. The restriction may be due to blockage such as an object, a bent tube, or a leak, for example, all of these tending to significantly reduce the water flow.

If, however, the water tubes slowly become contaminated such as by algae buildup or the like, a differential temperature will increase relatively slowly with time and rule r592, uses AND function 426 to convert the slow increase and the hot hydrogen side oil determination into a confidence level that the hot oil is due to tube fouling in the cooler, node m469.

Under normal operating conditions, the temperature of the outlet cooler water should be greater than the temperature of the inlet cooler water to reflect the heat removed from the hydrogen side oil. If there is no differential temperature, and if the hydrogen side oil is hot, rule r591 uses AND function 428 to conclude that there may be something wrong with the baffles within the cooler, node m468, in which case the hot oil would not be directed across the cooling coils properly. The cooler generally has a bypass valve (not illustrated in Figure 2) and if this valve is opened, the hot oil could be bypassing the cooler. This condition is also implied by node m468.

All of the abnormal conditions indicated at nodes m468 to m471 provide reasons for the hydrogen side sealing oil to be hot. Rule r596 uses OR function 430 to conclude that the reason for the hot oil is known, node h459. Using AND function 432 of rule 589, if no reason is known for the oil being hot and it is indeed hot, it is concluded that since none of the previously described reasons are present, the hot oil must be due to an inadequate water flow in the cooler, node m473. This conclusion is additionally supported by rule r4149 if the differential temperature between the inlet and outlet water is high.

If it is concluded that there is low water flow, a procedure P6 is indicated to the operator to increase the flow of water to the cooler and when that is done, a 1 is entered through operation of the keyboard into node hswfi indicating that the hydrogen side water flow has been increased. Rule r4106 maps this value into a confidence level that the flow has been increased, node h563. Rule r4134 which would have a negative sufficiency factor would subtract from the confidence level in the low water flow conclusion of m473.

FIG. 17 (A & B)

Figures 17A and 17B illustrate various conditions relating to the valves on drain regulator 64 and the pressure equalizing valves 210 and 217.

During normal operation, the pressure equalizing valves 210 and 217 should operate to make the hydrogen side oil pressure equal to the air side oil pressure. If one pressure is greater than the other, more or less oil will flow into the defoaming tanks, the results of which are seen in the drain regulator tank 64. If too much oil is deposited in the defoaming tanks, the oil level in the drain regulator will rise thereby opening drain valve 231 to compensate, in which case sensor DRD63 provides an output signal indicative of the open condition of the valve. If there is less than normal flow into the drain regulator, fill valve 232 will be opened such that sensor DRFXD provides an output signal indicative of the open condition of the valve.

Rule r4113 in Fig. 17A uses logic functions 440 to 442 to conclude, at node h566, that either the drain valve 231 is open and the feed valve 232 is closed, or conversely, that the feed valve is open and the drain valve is closed. If either is the case, then one or both of the pressure equalizing valves 210 and 217 are probably defective, this conclusion at node m490 being reached by means of rule r4120. If the air side oil is entering the hydrogen side defoaming tanks, the air can find its way into the generator housing and a low hydrogen purity indication provided by rule r4112 would additionally support the defective valve conclusion.

The existence of the defective valve indication functions to signal the operator to initiate procedure P7 whereby the pressure differential gauges ga4610 and ga4630 are to be read and their values entered into the system. With pressure equalizing valves 210 and 217 operating properly, the hydrogen side and air side oil pressures should be equal and the gauges, providing an indication of the pressure difference, should therefore read zero. Rules r4116 and r4118 (Fig. 17B) convert the respective gauge readings into a conclusion, at nodes h564 and h565 that the readings are other than zero. This conclusion is presented to AND function 444 of rule r4115, to AND function 445 of rule r4119, to AND function 446 of rule r4117 and to AND function 447 of rule r4114.

For rule r4115, gauge ga4610 does not read zero, while gauge ga4630 does (i.e. the negation of does not read zero). Accordingly, these two factors lead to the conclusion at node m492 that valve 210, to which gauge ga4610 is connected, is defective or out of adjustment. This determination, however, is valid only if the hydrogen side pump is running and, accordingly, the evidence of node m400 is included in the determination.

Rule r4119, at node m494, arrives at the same conclusion with respect to valve 217 using similar evidence. If both valves happen to be defective, and the hydrogen side pump is still operating, rule r4117 will convert this input into the conclusion that both valves are defective or out of adjustment, node m493.

If one of the drain or feed valves, 231 and 232 respectively, is open and the other closed, or vice versa, but both differential pressure gauges are zero, then it is likely that the fault lies with the drain or feed valves 231 or 232, node m491. This scenario is depicted by rule r4114 using AND function 447.

Thus, if it has been determined that one or both valves are defective, then the need to display the general observation of defective pressure regulating valves provided at node m490 (Fig. 17A) is no longer desired. Accordingly, propagation of this conclusion may be terminated by changing the sufficiency of rule r4120 by means of a parametric alteration rule modification. This may be accomplished in one embodiment by having nodes m491 to m494 generate individual parametric alteration rules for changing the sufficiency. Alternatively, and as indicated in Figure 17B, rule r4121 can combine all of the outputs of nodes m491 to m494 using OR function 450 to conclude that the defective valve or valves are known, node h575, in which case parametric alteration rule pr4920 operates on rule r4120 to effectively cut off propagation of the conclusion of node m490.

Accordingly, there has been described a diagnostic system for arriving at certain conclusions relative to the operating condition of a gas cooled electric generator sealing oil system while the generator and sealing oil system are on-line. The abnormal conditions described by way of example are representative of many conditions which may be diagnosed and presented to an operator with various degrees of confidence so that proper corrective action, if needed, may be taken.

Various illustrations have been given of the validation of conclusions resulting from sensor readings. In general, such validation would be desirable for the majority of sensor readings and would be performed using one or more of the techniques described herein.

APPENDIX A

Hypothesis Number	Brief Explanation	Figure in Which First Derived
h400	Hydrogen side pump 50h is off.	7A
h401	High air side oil pressure on the exciter end according to gauge ga4610.	7B
h402	High air side oil pressure on the turbine end according to gauge ga4610.	7B
h403	The oil pressure as read by gauge ga4650 is approximately equal to the hydrogen gas pressure.	7B
h404	Air side pump 50a is off (validated).	8A
h405	The oil pressure at the output of the air side pump is low according to gauge ga4640.	8B
h406	The oil pressure at the output of the air side pump is normal according to gauge ga4640.	8B
h407	The oil pressure in the air side line delivering oil to the gland seals is low according to gauge ga4620.	8B
h409	The hydrogen side pump 50h is off (validated).	7A
h410	The turbine backup pressure is low according to switch SOB63.	8A
h413	The oil level in drain regulator 64 is low according to sensor DRT71.	9
h414	The oil level is high in the turbine end defoaming tank 62 according to sensor DTT71.	10

h416	The hydrogen side oil is cold according to sensor TC2520.	15A
h417	The hydrogen side oil is cold according to thermometer tm520.	15A
h418	First validation of cold hydrogen side oil.	15A
h419	First validation of hot hydrogen side oil.	15A
h420	The hydrogen side oil is hot according to sensor TC2520.	15A
h428	Neither the hydrogen side oil nor air side oil is hot.	14
h432	The differential pressure between the air side supplied oil and the hydrogen pressure is approximately 5 psi according to differential pressure sensor ASOHXD.	11
h434	The differential pressure between the air side supplied oil and the hydrogen pressure is between 8 and 12 psi according to differential pressure sensor ASOHXD.	11
h438	The differential pressure between the air side supplied oil and the hydrogen pressure is high according to differential pressure sensor ASOHXD.	11
h441	There is disagreement between the readings of thermocouple TC2520 and thermometer tm520 in determining whether the hydrogen side oil temperature is hot.	15B
h442	The hydrogen side oil is hot according to an operator who has felt the oil delivery pipe.	15B
h446	Thermocouple TC2520 is out of range.	15A
h448	The thermocouple TC2520 and	15A

	thermometer tm520 readings do not agree.	
h450	The differential pressure derived from the exciter end oil pressure sensor ASOEXD and a hydrogen pressure transducer is between 5 and 8 psi.	12
h453	Feed valve 232 at the drain regulator 64 is open according to sensor DRFXD.	9
h454	Drain valve 231 draining oil from drain regulator 64 is open according to sensor DRD63.	9
h455	Oil is backing up out of the drain regulator 64 as determined by sensor DRI71.	9
h457	The differential pressure derived from the exciter end oil pressure sensor ASOEXD and a hydrogen pressure transducer is between 8 and 12 psi.	12
h459	The hydrogen side oil is hot and the reason for its being hot is known.	16B
h460	There is high air side pressure at the exciter and turbine ends as determined by gauges ga4610 and ga4630.	7B
h461	The differential pressure across the hydrogen side filter 58h is high according to sensor HSOFXD.	7A
h462	The differential pressure across the air side filter 58a is high according to sensor HSOFXD.	13
h464	The oil level in drain regulator 64 is high according to sensor olg.	9
h465	Feed valve 232 for drain regulator 64 is open while drain valve 231 is closed.	9
h468	Indicates a suspicious condition at the drain regulator according to levels and	9B

	open or closed conditions of feed and drain valves.	
h469	The drain valve 231 and feed valve 232 of drain regulator are both open.	9
h472	The oil level in the exciter end defoaming tank 60e is high according to sensor DTE71.	10
h474	A significant difference exists between the exciter end air side pressure sensor ASOEXD and turbine end sensor ASOTXD.	12
h478	The differential pressure derived from the exciter end oil pressure sensor ASOEXD and a hydrogen pressure transducer is less than 0 psi.	12
h479	The differential pressure derived from the exciter end oil pressure sensor ASOEXD and a hydrogen pressure transducer is approximately 5 psi.	12
h480	The rate of change of the exciter end differential pressure is decreasing.	12
h483	The hydrogen side oil is cold according to thermocouple TC2520 (second validation).	15A
h484	The hydrogen side oil is hot according to thermocouple TC2520 (second validation).	15A
h490	A significant difference exists between the thermocouple TC2520 measuring the temperature of the hydrogen side oil and thermocouple TC2510 measuring the temperature of the air side oil.	15A
h492	The difference in temperature between the outlet and inlet cooling water for cooler 54h as measured by thermocouples TC2526 and TC2525 is high.	16B
h493	The inlet water to cooler 54h as measured by thermocouple TC2525	16A

	is hot.	
h494	The inlet water to cooler 54h as measured by thermocouple TC2525 is cold.	16A
h499	The difference in temperature between the outlet and inlet cooling water for cooler 54h as measured by thermocouples TC2526 and TC2525 is approximately 0.	16B
h500	The differential temperature between the outlet and inlet cooling water to cooler 54h as measured by thermocouples TC2526 and TC2525 is slowly increasing with time.	16B
h501	The differential temperature between the outlet and inlet cooling water to cooler 54h as measured by thermocouples TC2526 and TC2525 is rapidly increasing with time.	16A
h502	The purity of the hydrogen within the generator housing is low.	14
h503	There is high humidity within the generator housing.	14
h504	There is an oil leak at the exciter end or turbine end of the generator.	14
h505	Oil has entered the generator housing but the oil is not hot.	14
h506	There is disagreement between the exciter and turbine end pressure sensors ASOEXD and ASOTXD however the sensed pressure compared with the hydrogen pressure is approximately 8 psi.	8A
h509	The rate of change of the turbine end differential pressure is decreasing.	12
h510	The rate of change of the differential pressure as measured by sensor ASOHXD is negative.	11

h512	The maximum differential pressure measured by either ASOEXD or ASOTXD is approximately 8 psi.	12
h513	The differential pressure across the hydrogen side filter 58h is approximately 0 as measured by sensor HSOFXD.	7A
h518	A disagreement exists since the differential pressure across the hydrogen side filter 58h and the hydrogen side cooler water differential temperature indicates a condition opposite to that indicated by sensor HSO63 across hydrogen side pump 50h.	7A
h520	A problem exists in the exciter end according to gauges ga4610 and ga4630.	7B
h522	There is agreement between the exciter and turbine end pressure sensors ASOEXD and ASOTXD however the sensed pressure compared with the hydrogen pressure is approximately 8 psi.	8A
h523	A disagreement exists because pressure conditions as measured by the exciter and turbine end sensors ASOEXD and ASOTXD indicate a contrary condition of the air side pump 50a as indicated by sensor ASO63.	8A
h526	The oil level in the exciter end defoaming tank is high and the oil is hot.	10
h527	The oil level in the turbine end defoaming tank 6ot is high and the oil is hot.	10
h531	The differential pressure as measured by sensor ASOHXD is less than 5 psi.	11
h535	The differential pressure derived from the exciter end oil pressure sensor ASOEXD and	12

	a hydrogen pressure transducer is approximately 8 psi.	
h536	The differential pressure derived from the exciter end oil pressure sensor ASOEXD and a hydrogen pressure transducer is between 0 and 5 psi.	12
h540	The differential pressure derived from the turbine end oil pressure sensor ASOTXD and a hydrogen pressure transducer is approximately 12 psi.	12
h541	The differential pressure derived from the turbine end oil pressure sensor ASOTXD and a hydrogen pressure transducer is between 8 and 12 psi.	12
h542	The differential pressure derived from the turbine end oil pressure sensor ASOTXD and a hydrogen pressure transducer is approximately 8 psi.	12
h543	The differential pressure derived from the turbine end oil pressure sensor ASOTXD and a hydrogen pressure transducer is between 5 and 8 psi.	12
h549	The differential pressure at the exciter end is less than 12 psi.	13
h550e	The differential pressure at the exciter end is less than 8 psi.	13
h560	The hydrogen side oil is hot according to thermometer tm520.	15A
h563	The flow of water to the hydrogen side of the cooler 54h has been increased.	16B
h564	The differential pressure gauge ga4610 at the exciter end does not read zero.	17
h565	The differential pressure gauge ga4630 at the turbine end does	17

	not read zero.	
h566	Either the drain valve 231 is open and feed valve 232 is closed or vise versa.	17
h567	The hydrogen side pump 50h is off according to gauge readings.	7B
h568	The difference between the air side oil and hydrogen pressure is less than 8 psi.	8A
h569	The air side pump 50a is off according to sensor AS063.	8A
h570	The oil level in both the exciter and turbine end defoaming tanks 60e and 60t is high according to sensors DTE71 and DTT71.	10
h575	One or more defective valves of the group including drain and feed valves 231 and 232 and pressure regulating valves 210 and 217 is known.	17
h576	The difference in temperature between the outlet and inlet cooling water for cooler 54h as measured by thermocouples TC2526 and TC2525 is low.	16B

Claims

1. Diagnostic apparatus for a multi-component gas-cooled electric generator seal oil system (20) wherein the generator shaft (18) is sealed against the escape of the cooling gas by means of spaced-apart gland seals (44e, 44t) and wherein sealing oil is supplied to the gland seals, of the type comprising:
a plurality of sensors connected to sense predetermined operating parameters of said seal oil system, while on-line, and to provide respective corresponding output signals; characterized by:
computer means (22) including a rule base memory for diagnosing the on-line operating condition of said seal oil system (20);
said rule base including rules (104 – Figure 4) linking a preceding evidence node (100) with a consequent hypothesis node (102);
a plurality of said evidence nodes constituting sensor nodes;
said apparatus including means for inputting said on-line sensor signals into said sensor nodes;
means (28) for additionally inputting operator generated values into selected ones of said sensor nodes.

2. Apparatus according to claim 1 which includes:
at least one thermometer (tm 510, 520) connected to provide a reading of seal oil temperature; wherein said operator generated value is the temperature reading of said thermometer.

3. Apparatus according to claim 1 which includes:
at least one pressure gauge (ga 4610, 4620 ... 4650) connected to provide a reading of seal oil pressure; wherein
said operator generated value is the pressure reading of said pressure gauge.

Patentansprüche

1. Fehlersuchgerät für ein Mehrfachkomponenten-Dichtölsystem eines gasgekühlten elektrischen Generators, worin die Generatorwelle (18) gegen Austreten von Kühlgas durch im Abstand angeordnete Spritzdichtungen (44e, 44t) verschlossen wird und worin Dichtöl durch die Spritzdichtungen zugeführt wird, wobei eine Vielzahl von Sensoren angeschlossen sind, um vorbestimmte Bedienungsparameter des Dichtölsystems zu fühlen, während on-line, und um entsprechende einschlägige Ausgangssignale zu liefern, dadurch gekennzeichnet, daß
eine Computereinrichtung (22) vorgesehen ist, die einen Linienbasisspeicher zur Diagnose der on-line Arbeitsbedingungen des Dichtölsystems (20) aufweist;
diese Linienbasis (104, Figur 4) mit Linien versehen ist, die einen vorhergehenden Nachweis-Knotenpunkt (100) mit einem folgenden Hypothese-Knotenpunkt (102) verbinden;
eine Vielzahl der Nachweis-Knotenpunkte, die Sensor-Knotenpunkte bilden;
das Gerät Mittel zum Eingeben der on-line Sensorsignale in die Sensor-Knotenpunkte aufweist;
Mittel (28), zum zusätzlichen Eingeben von durch die Bedienungsperson geschaffenen Werten in einen ausgewählten der Sensor-Knotenpunkte, vorgesehen sind.

2. Gerät nach Anspruch 1, dadurch gekennzeichnet, daß
mindestens ein Thermometer (tm 510, 520) angeschlossen ist, um eine Anzeige der Dichtöltemperatur zu liefern; wobei der durch die Bedienungsperson geschaffene Wert die Temperaturanzeige des Thermometers ist.

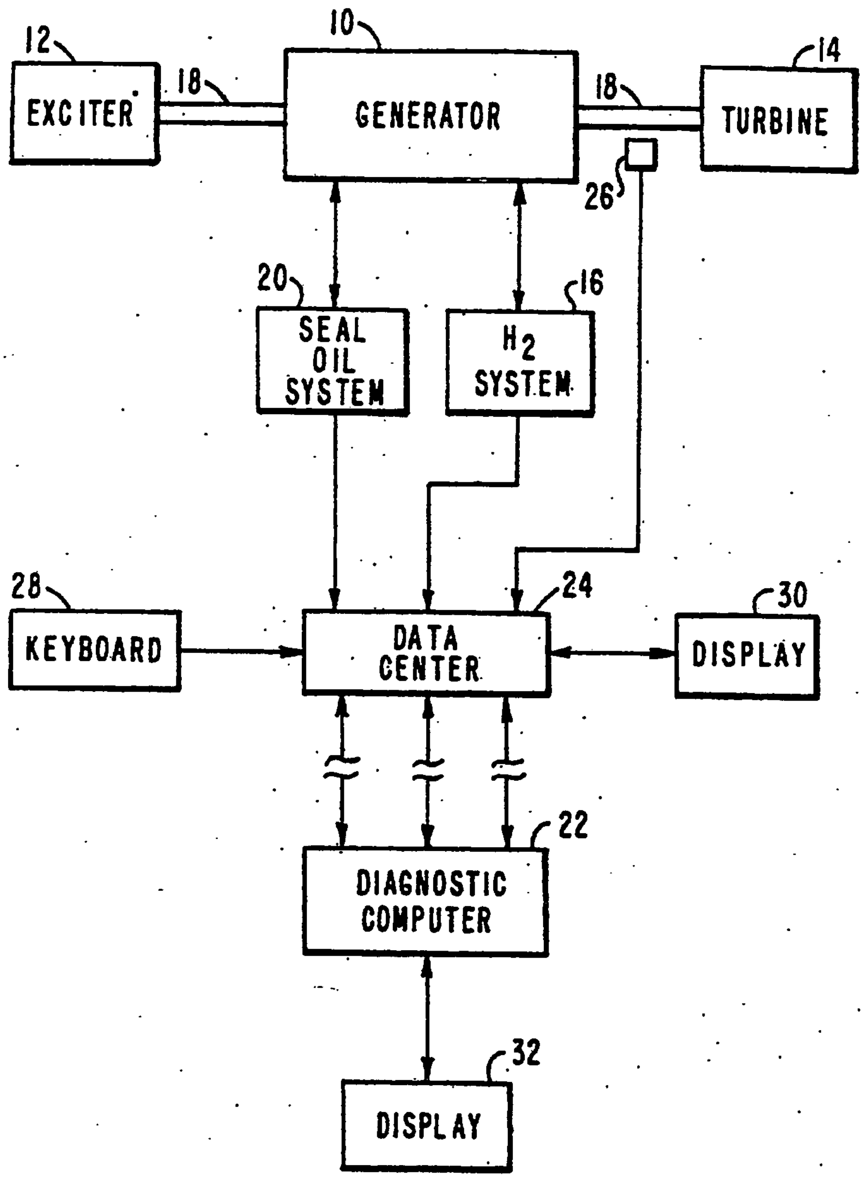
3. Gerät nach Anspruch 1, dadurch gekennzeichnet, daß
mindestens ein Druckmesser (ga 4610, 4620, ... 4650) angeschlossen ist, um eine Anzeige des Dichtöldruckes zu liefern;
wobei der von der Bedienungsperson geschaffene Wert die Druckanzeige des Druckmessers ist.

Revendications

1. Appareil de diagnostic pour système (20) à huile d'étanchéité multi-éléments pour générateur électrique refroidi par gaz, dans lequel l'abre (18) du générateur est rendu étanche à l'aide de garnitures d'étanchéité (44e à 44t) espacées les unes des autres pour empêcher le gaz de refroidissement de s'échapper, et dans lequel l'huile d'étanchéité est fournie aux garnitures d'étanchéité, du type comprenant:
une pluralité de capteurs monté pour détecter des paramètres de fonctionnement prédéterminés dudit système d'huile d'étanchéité pendant qu'il est en service, et pour fournir des signaux de sortie respectifs correspondants; caractérisé par:
un moyen formant calculateur (22) comportant une mémoire à base de règles pour diagnostiquer l'état de fonctionnement en service dudit système (20) à huile d'étanchéité;
ladite base de règles comportant des règles (104 – Figure 4) liant un nœud précédent de mise en évidence (100) à un nœud résultant d'hypothèse (101);
une pluralité desdits nœuds d'évidence constituant des nœuds de capteurs;
ledit appareil comportant un moyen pour faire entrer dans lesdits nœuds de capteurs lesdits signaux de capteurs en service;
un moyen (28) pour introduire en outre dans certains desdits nœuds de capteurs choisis des valeurs produites par un opérateur.

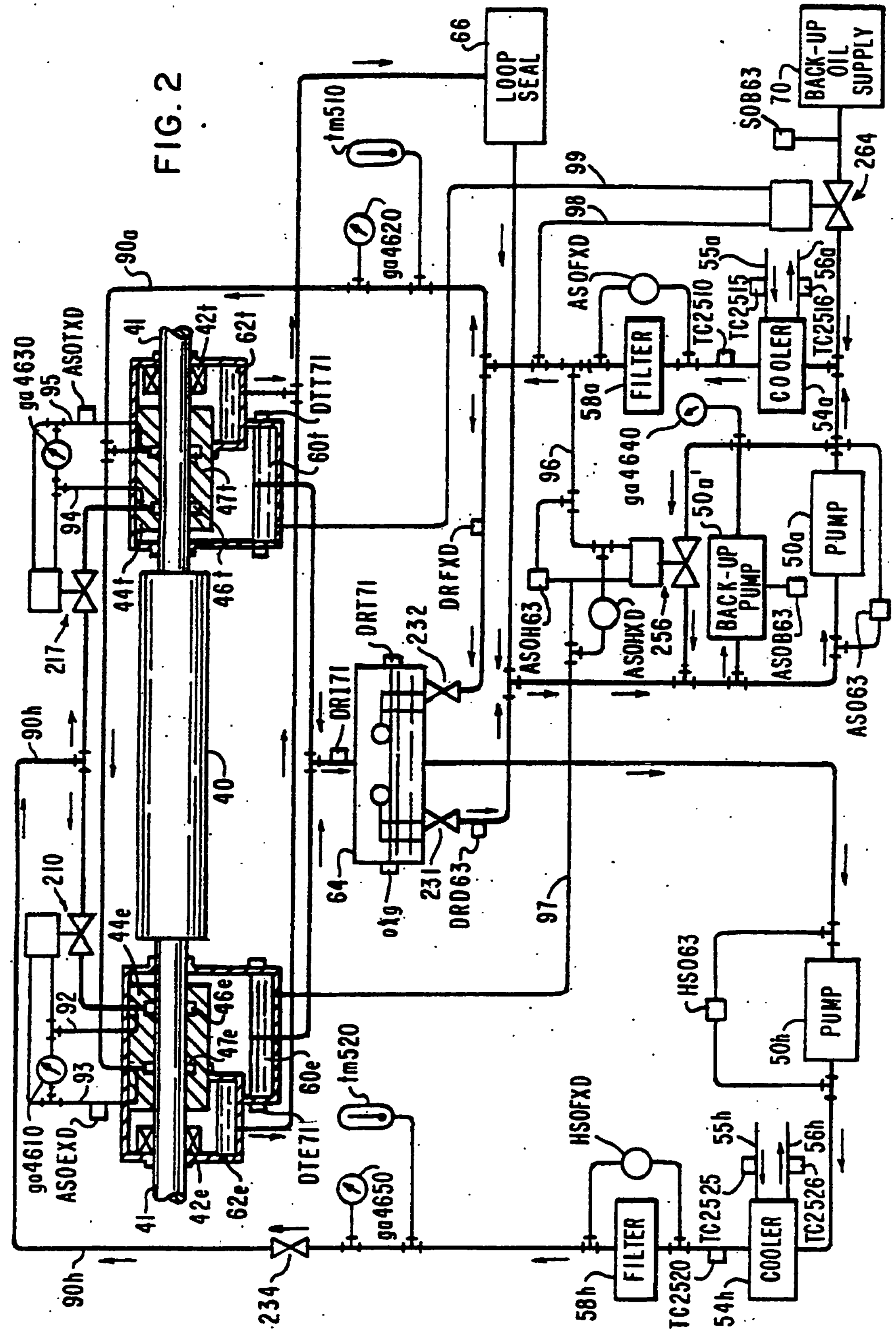
2. Appareil selon la revendication 1, comprenant:
au moins un thermomètre (tm 510, 520) monté pour fournir une indication de la température de l'huile d'étanchéité; dans lequel
ladite valeur produite par l'opérateur est la température indiquée par ledit thermomètre.

3. Appareil selon la revendication 1, qui comprend:
au moins un manomètre (ga 4610, 4620 ... 4650) monté pour fournir une indication de la pression de l'huile d'étanchéité; dans lequel
ladite valeur produite par l'opérateur est la pression indiquée par ledit manomètre.



12
EXCITER
18
10
GENERATOR
18
14
TURBINE
26
20
SEAL OIL SYSTEM
16
H_2 SYSTEM
28
KEYBOARD
24
DATA CENTER
30
DISPLAY
22
DIAGNOSTIC COMPUTER
32
DISPLAY

FIG. I


LOOP SEAL
66
BACK-UP OIL SUPPLY
70
SOB63
264
99
98
ASOFXD
TC2510
TC2515
55a
56a
TC2516
FILTER
COOLER
58a
54a
ga4640
96
50a'
BACK-UP PUMP
50a
PUMP
ASOB63
ASO63
ASOH63
ASOHXD
256
97
fm510
ga4620
90a
ga4630
95
ASOTXD
41
42t
62t
DTT71
60t
47t
46t
44t
94
217
DRFXD
DRT71
232
DRI71
90h
210
40
64
231
DRD63
otg
44e
92
46e
47e
93
ga4610
ASOEXD
60e
62e
42e
fm520
OTE71
ga4650
234
HSO63
50h
HSOFXD
55h
56h
TC2525
TC2526
FILTER
COOLER
58h
TC2520
54h
FIG. 2

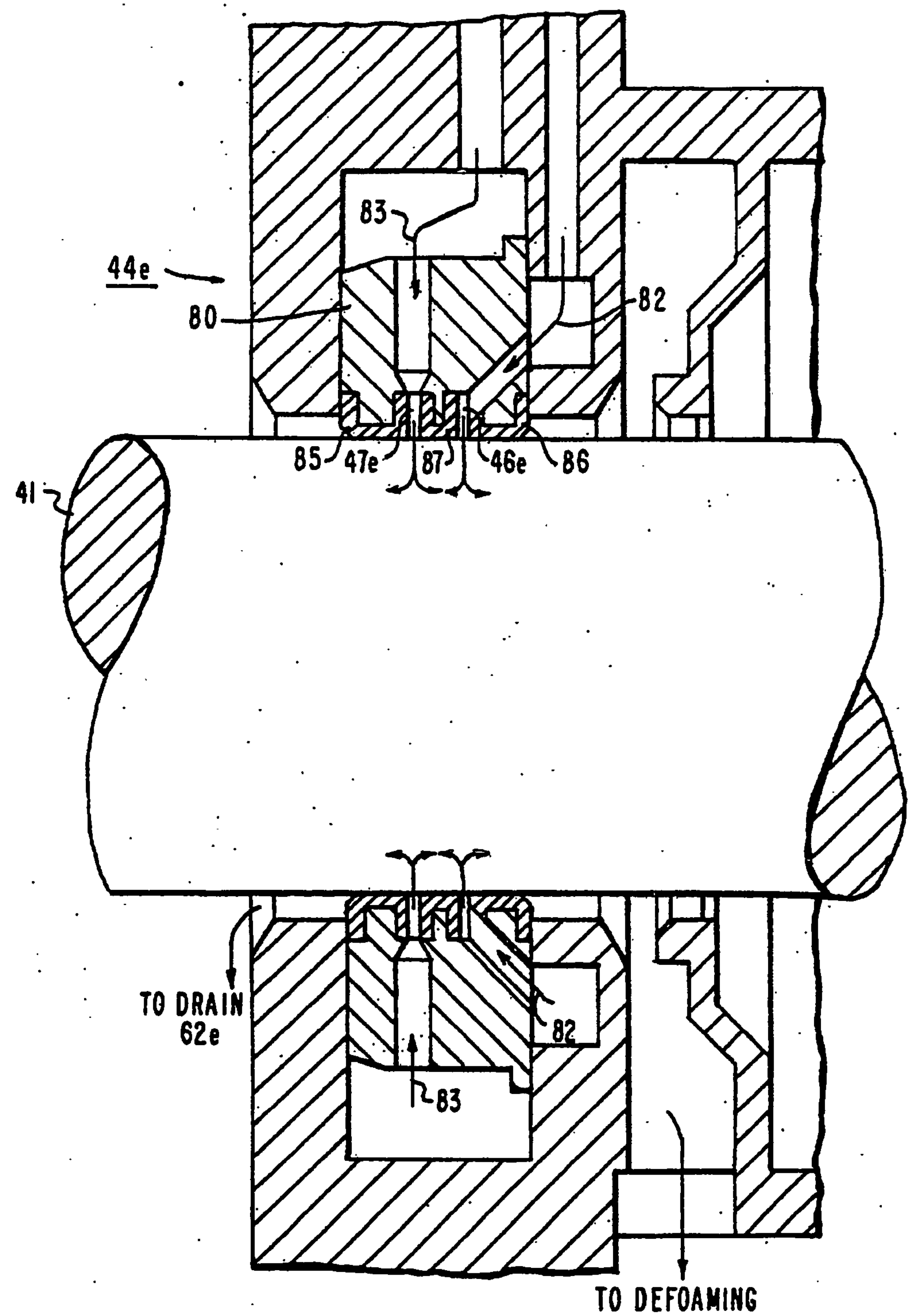

44e
80
83
82
85
47e
87
46e
86
41
TO DRAIN 62e
82
83
TO DEFOAMING TANK 60e

FIG. 3

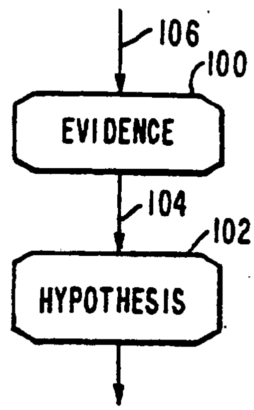


FIG. 4

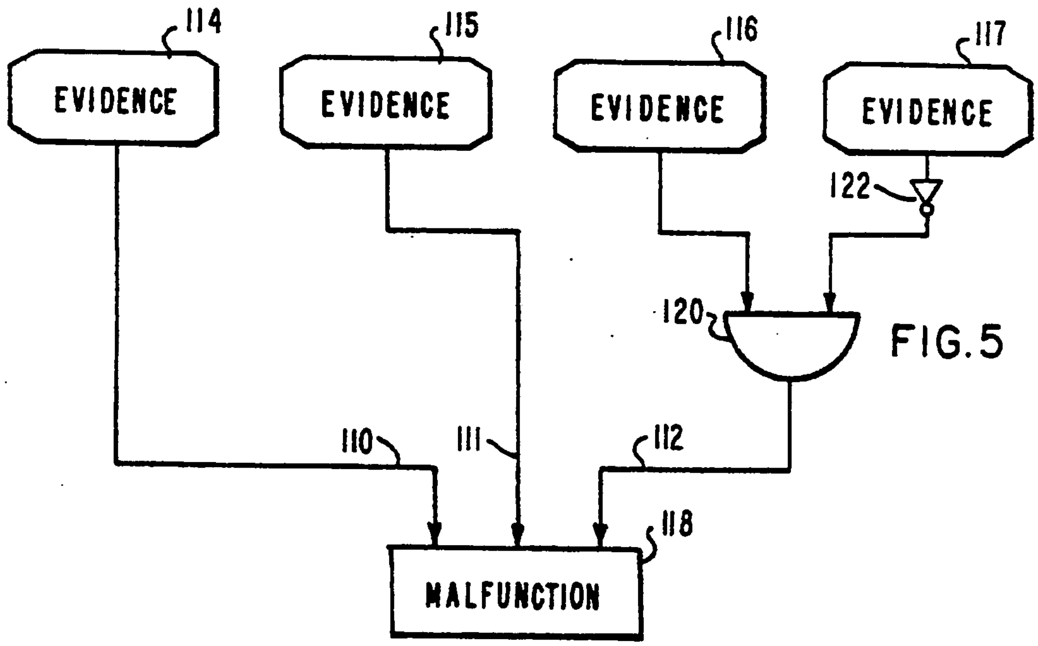


FIG.5

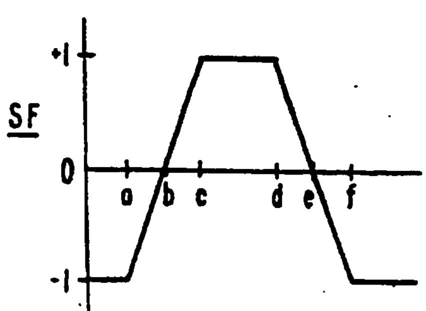


FIG.6A

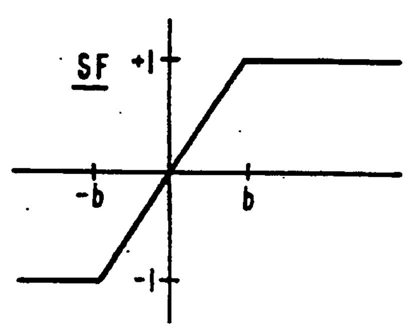


FIG.6B

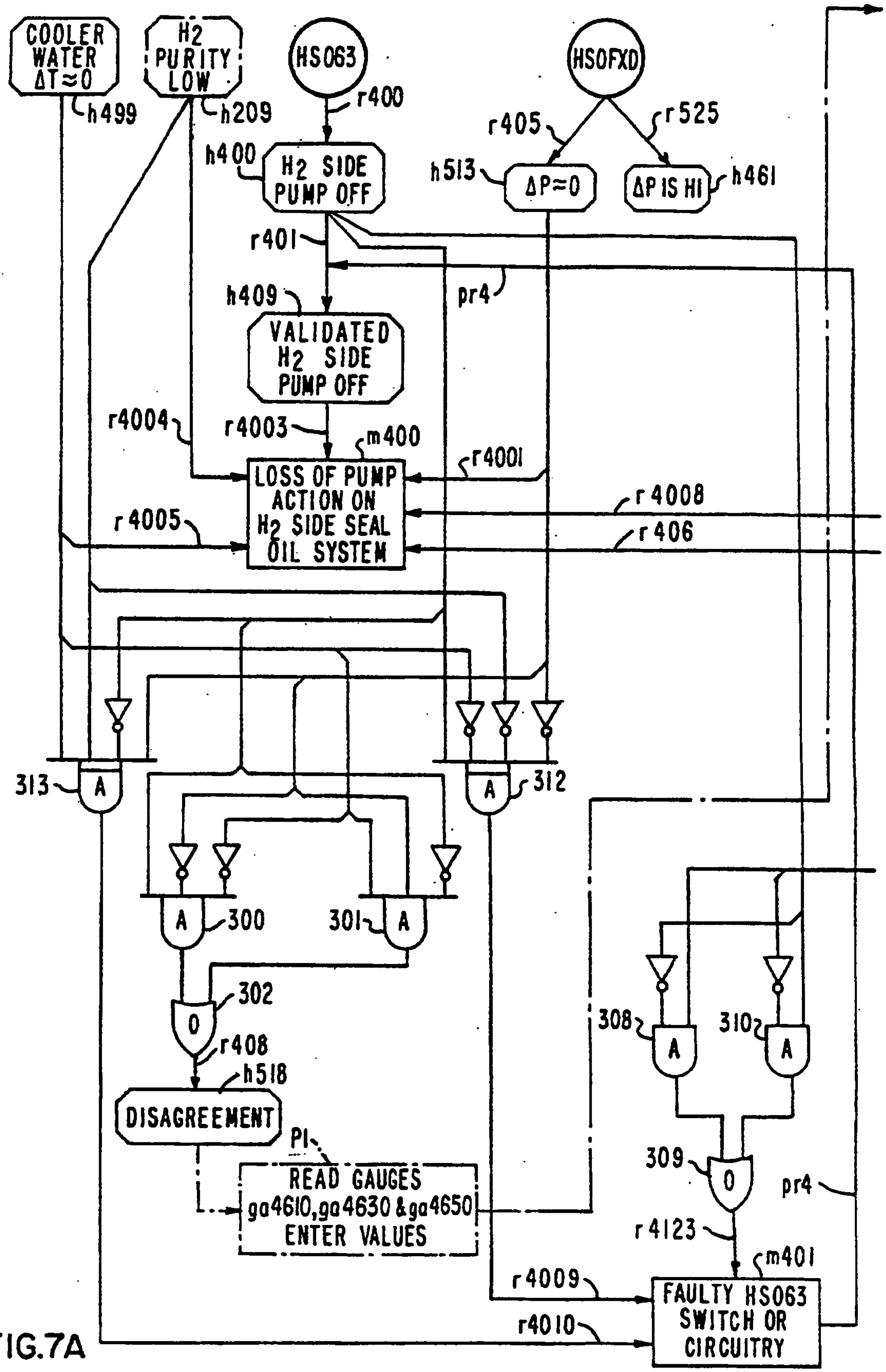

COOLER WATER ΔT≈0
h499
H2 PURITY LOW
h209
HS063
r400
HSOFXD
r405
r525
h400
H2 SIDE PUMP OFF
h513
ΔP≈0
ΔP IS HI
h461
r401
pr4
h409
VALIDATED H2 SIDE PUMP OFF
r4004
r4003
m400
LOSS OF PUMP ACTION ON H2 SIDE SEAL OIL SYSTEM
r4001
r4008
r406
r4005
313
A
312
300
301
302
0
r408
h518
DISAGREEMENT
P1
READ GAUGES ga4610, ga4630 & ga4650 ENTER VALUES
308
310
309
pr4
r4123
m401
r4009
r4010
FAULTY HS063 SWITCH OR CIRCUITRY

FIG.7A

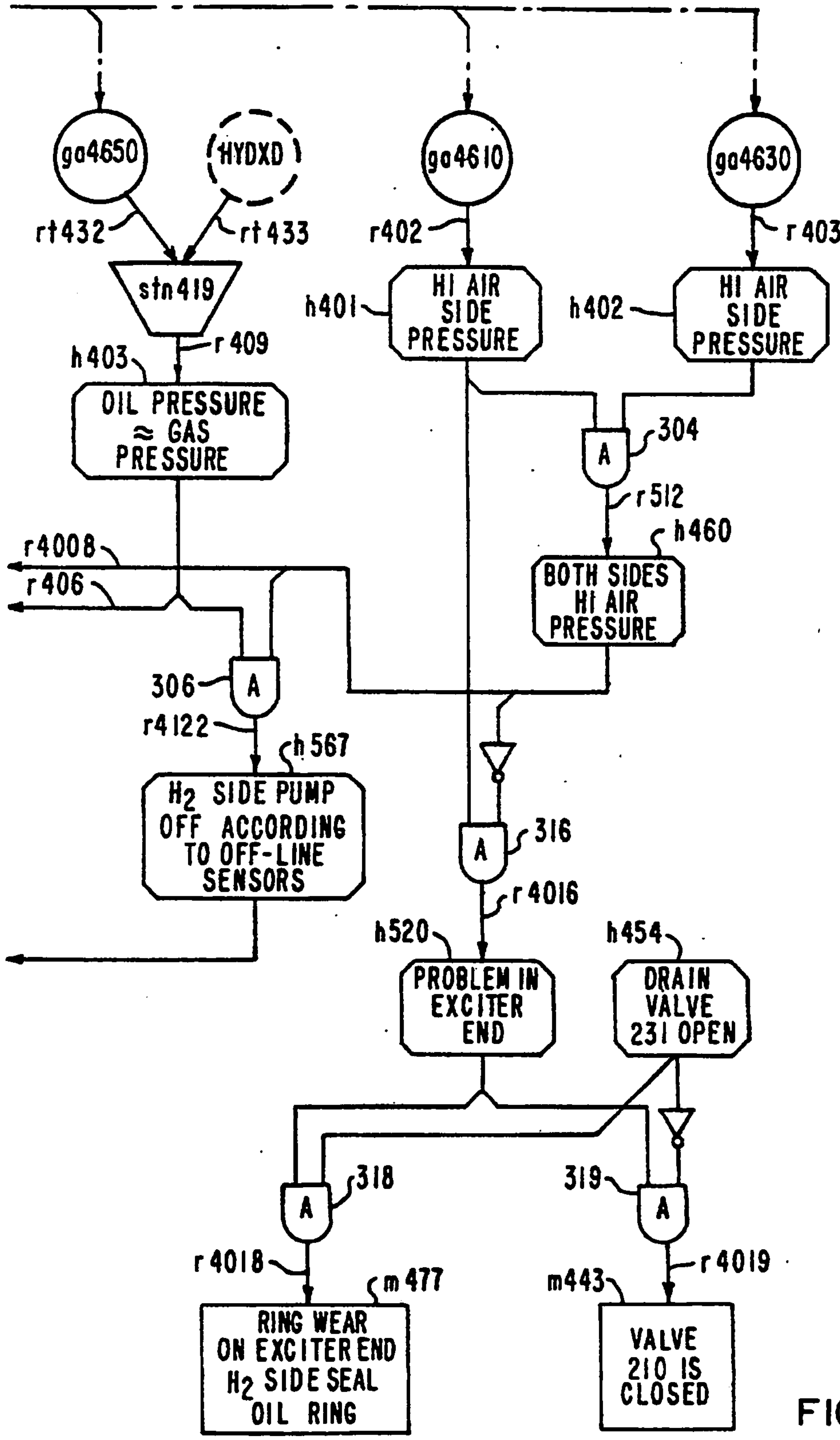

ga4650
HYDXD
ga4610
ga4630
rt432
rt433
r402
r403
stn419
h401
HI AIR SIDE PRESSURE
h402
HI AIR SIDE PRESSURE
r409
h403
OIL PRESSURE ≈ GAS PRESSURE
304
r512
h460
BOTH SIDES HI AIR PRESSURE
r4008
r406
306
r4122
h567
H_2 SIDE PUMP OFF ACCORDING TO OFF-LINE SENSORS
316
r4016
h520
PROBLEM IN EXCITER END
h454
DRAIN VALVE 231 OPEN
318
319
r4018
m477
RING WEAR ON EXCITER END H_2 SIDE SEAL OIL RING
m443
r4019
VALVE 210 IS CLOSED

FIG. 7B

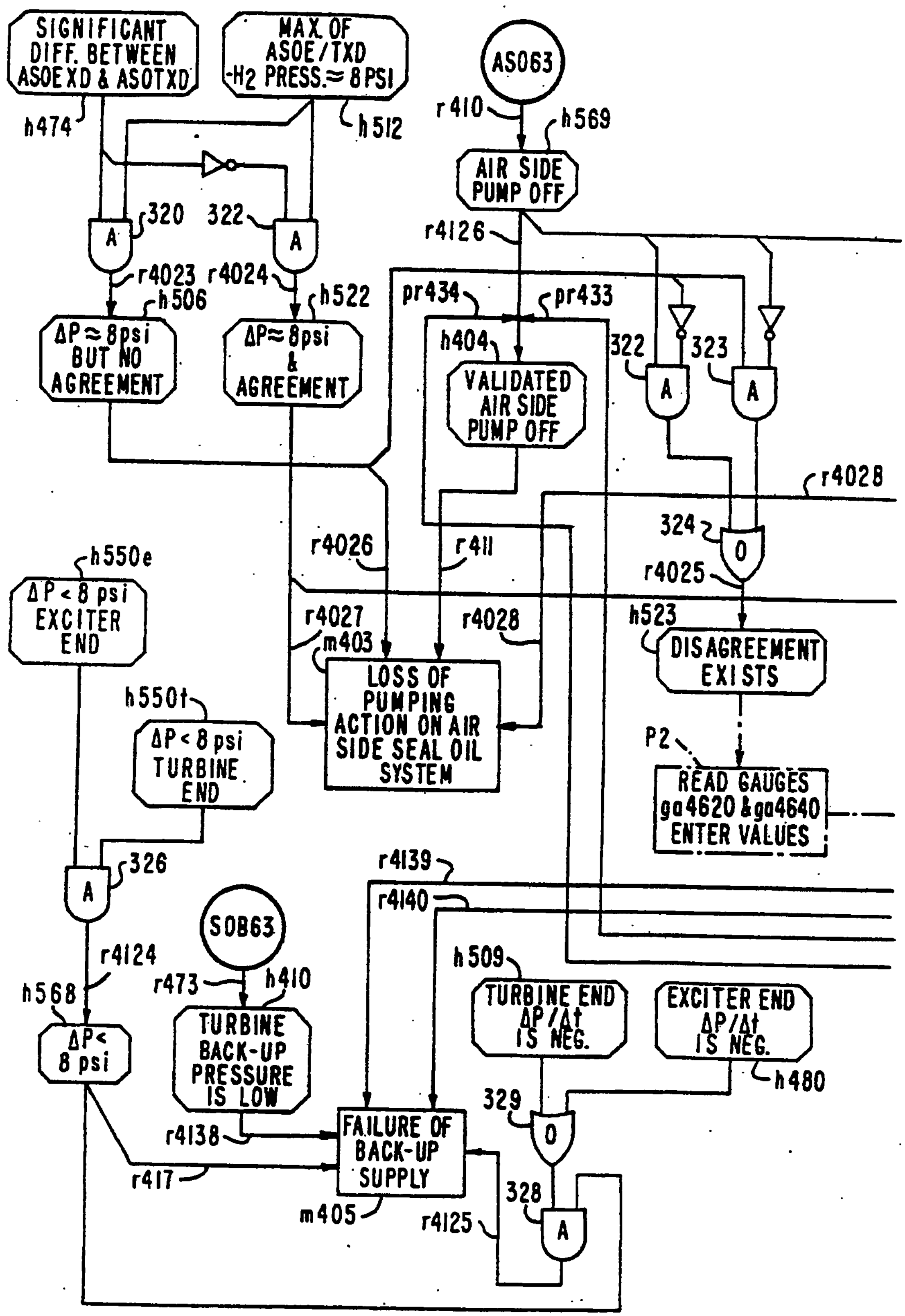

SIGNIFICANT DIFF. BETWEEN ASOEXD & ASOTXD
MAX. OF ASOE/TXD -H2 PRESS.≈ 8 PSI
AS063
h474
h512
r410
h569
AIR SIDE PUMP OFF
320
322
A
r4126
r4023
r4024
h506
h522
pr434
pr433
ΔP≈8psi BUT NO AGREEMENT
ΔP≈8psi & AGREEMENT
h404
VALIDATED AIR SIDE PUMP OFF
322
323
r4028
324
O
r4025
h550e
ΔP<8 psi EXCITER END
r4026
r411
r4027
m403
r4028
h523
DISAGREEMENT EXISTS
LOSS OF PUMPING ACTION ON AIR SIDE SEAL OIL SYSTEM
h550t
ΔP<8 psi TURBINE END
P2
READ GAUGES ga4620 & ga4640 ENTER VALUES
326
r4139
r4140
S0B63
r4124
h509
h568
r473
h410
ΔP< 8 psi
TURBINE BACK-UP PRESSURE IS LOW
TURBINE END ΔP/Δt IS NEG.
EXCITER END ΔP/Δt IS NEG.
h480
329
r4138
FAILURE OF BACK-UP SUPPLY
r417
328
m405
r4125

FIG. 8A

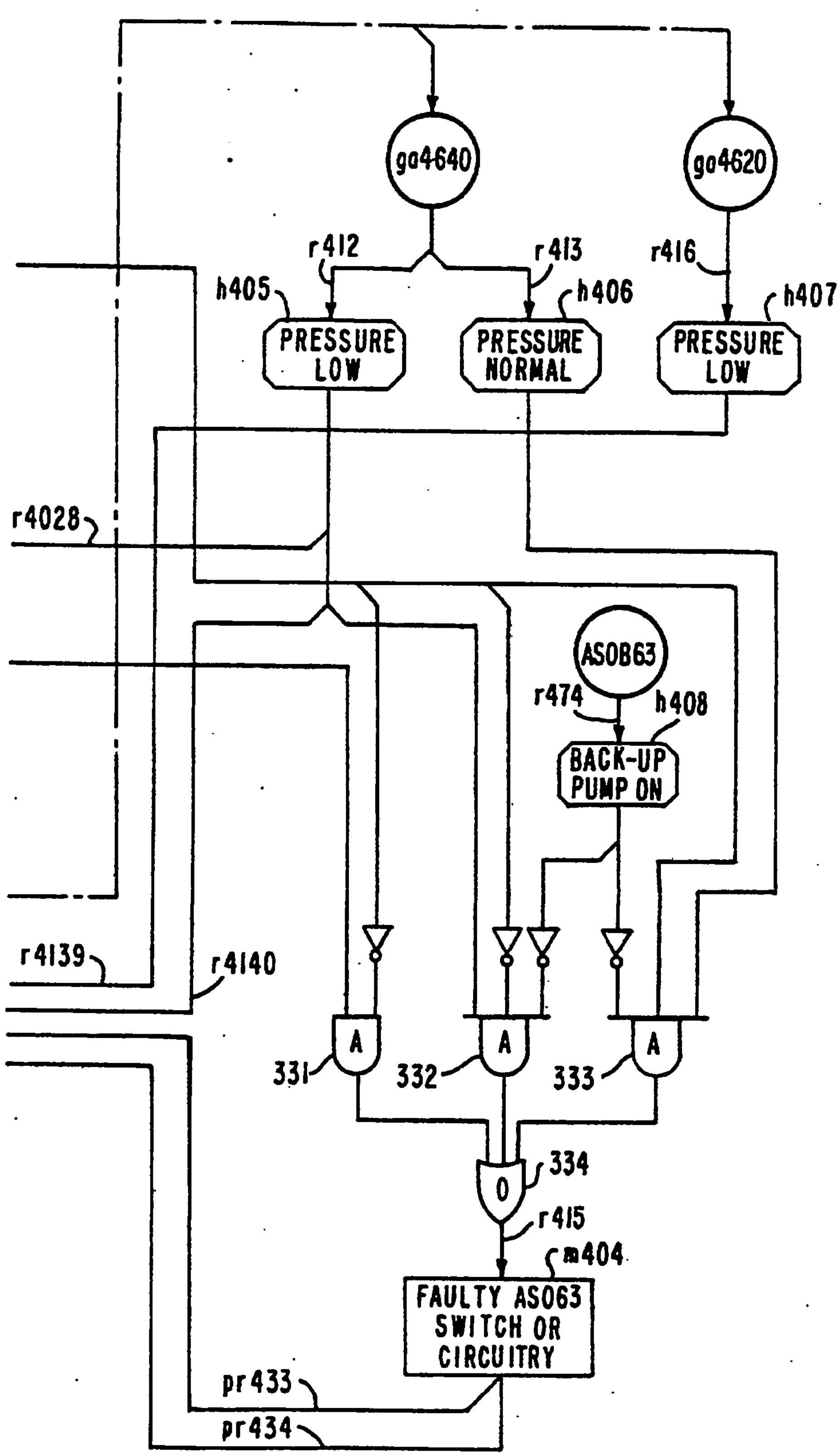

go4640
go4620
r412
r413
r416
h405
h406
h407
PRESSURE LOW
PRESSURE NORMAL
PRESSURE LOW
r4028
AS0B63
r474
h408
BACK-UP PUMP ON
r4139
r4140
A
A
A
331
332
333
0
334
r415
m404
FAULTY AS063 SWITCH OR CIRCUITRY
pr433
pr434

FIG.8B

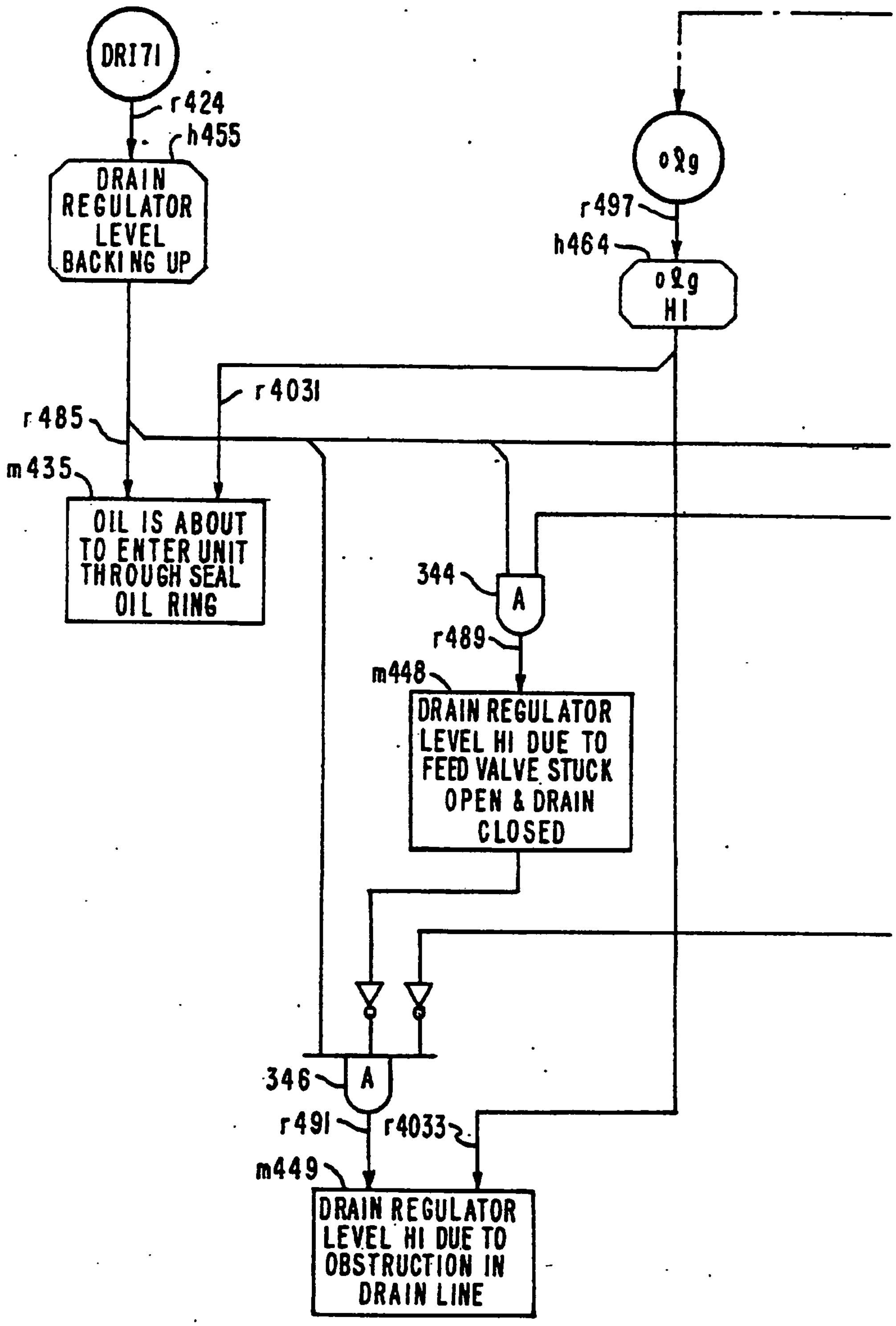

DRI71
r424
h455
DRAIN REGULATOR LEVEL BACKING UP
oℓg
r497
h464
oℓg HI
r4031
r485
m435
OIL IS ABOUT TO ENTER UNIT THROUGH SEAL OIL RING
344
A
r489
m448
DRAIN REGULATOR LEVEL HI DUE TO FEED VALVE STUCK OPEN & DRAIN CLOSED
346
A
r491
r4033
m449
DRAIN REGULATOR LEVEL HI DUE TO OBSTRUCTION IN DRAIN LINE

FIG.9A

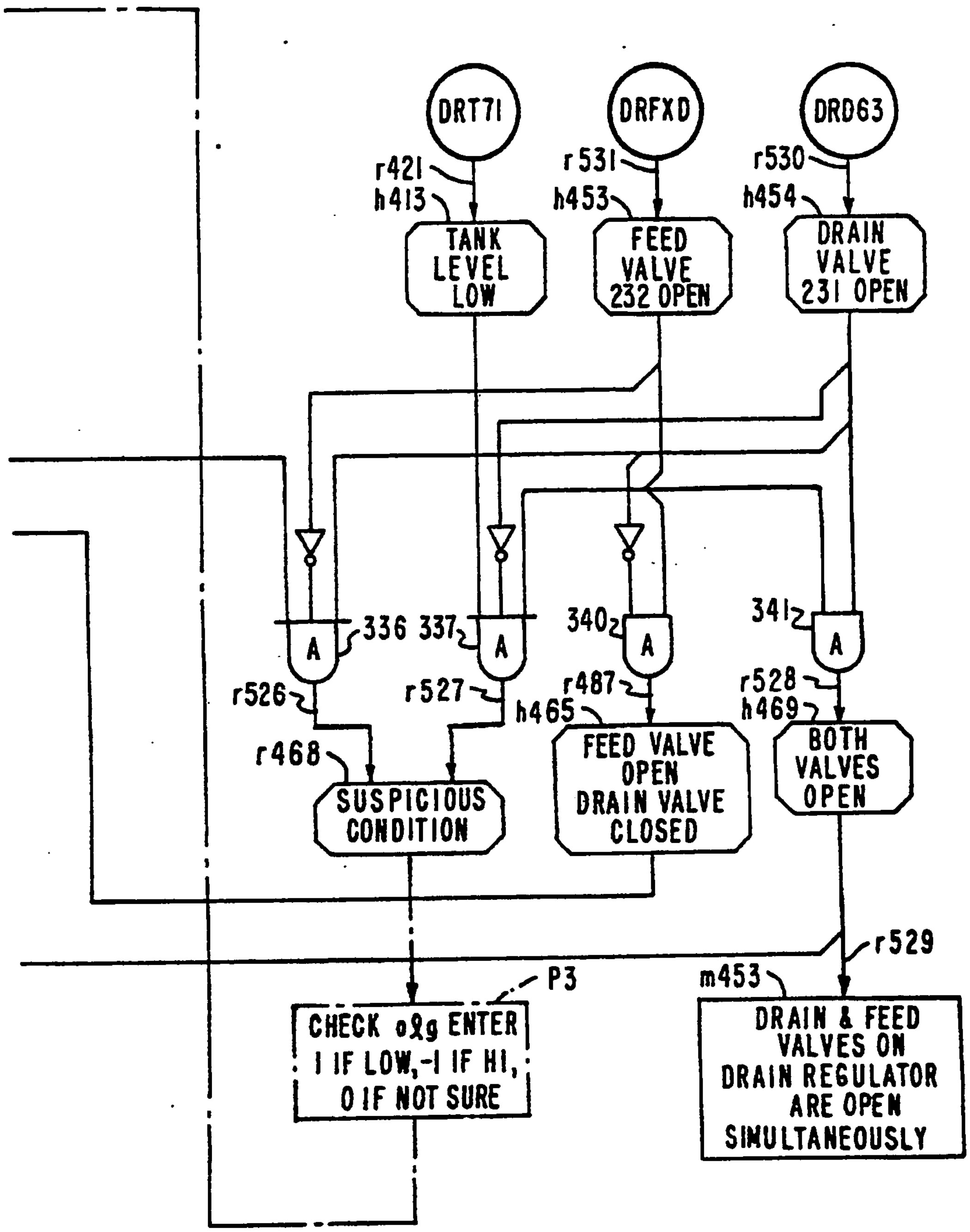

DRT71
DRFXD
DRD63
r421
h413
r531
h453
r530
h454
TANK LEVEL LOW
FEED VALVE 232 OPEN
DRAIN VALVE 231 OPEN
336
337
340
341
A
r526
r527
r487
h465
r528
h469
r468
SUSPICIOUS CONDITION
FEED VALVE OPEN DRAIN VALVE CLOSED
BOTH VALVES OPEN
r529
P3
m453
CHECK olg ENTER 1 IF LOW,-1 IF HI, 0 IF NOT SURE
DRAIN & FEED VALVES ON DRAIN REGULATOR ARE OPEN SIMULTANEOUSLY

FIG. 9B

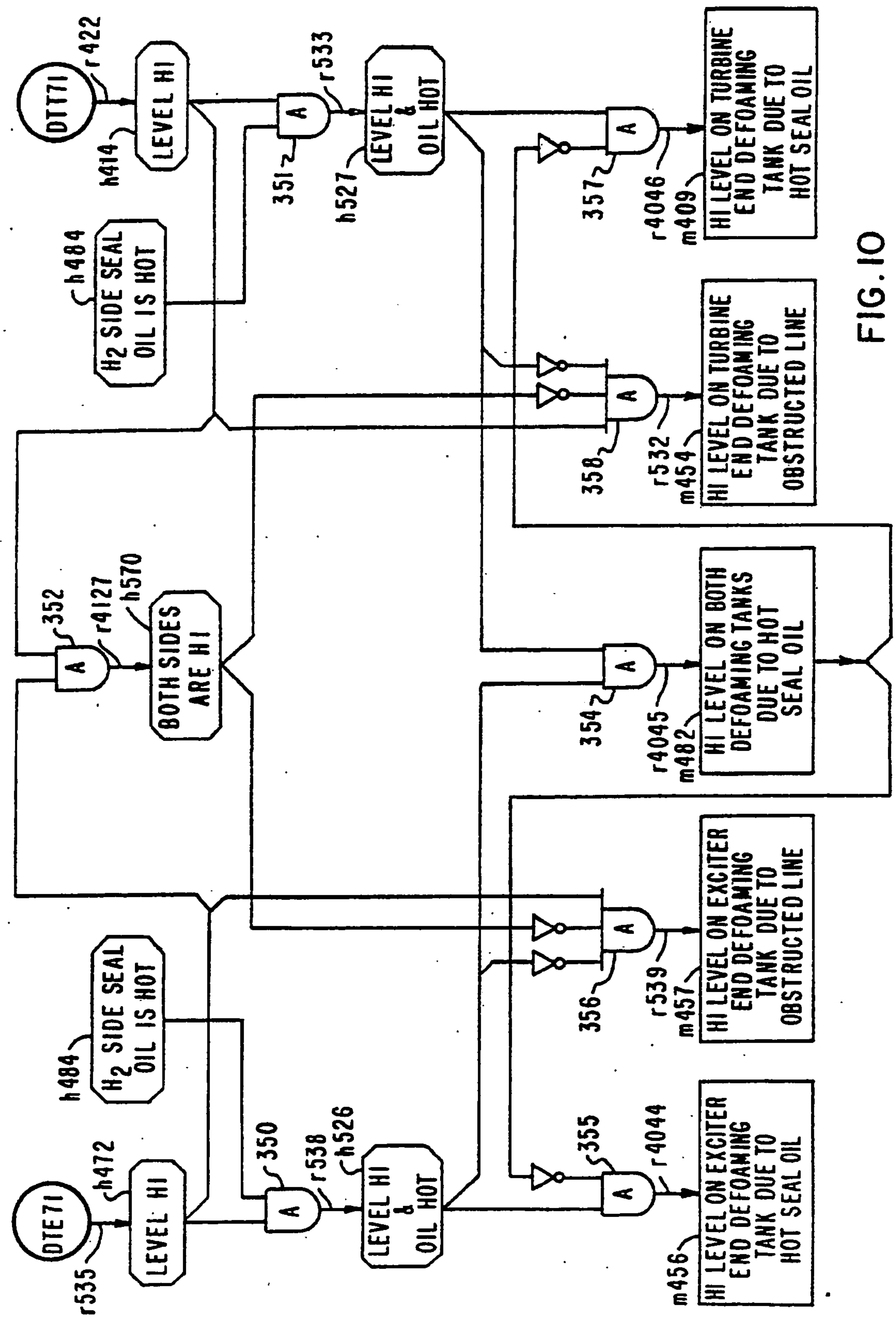
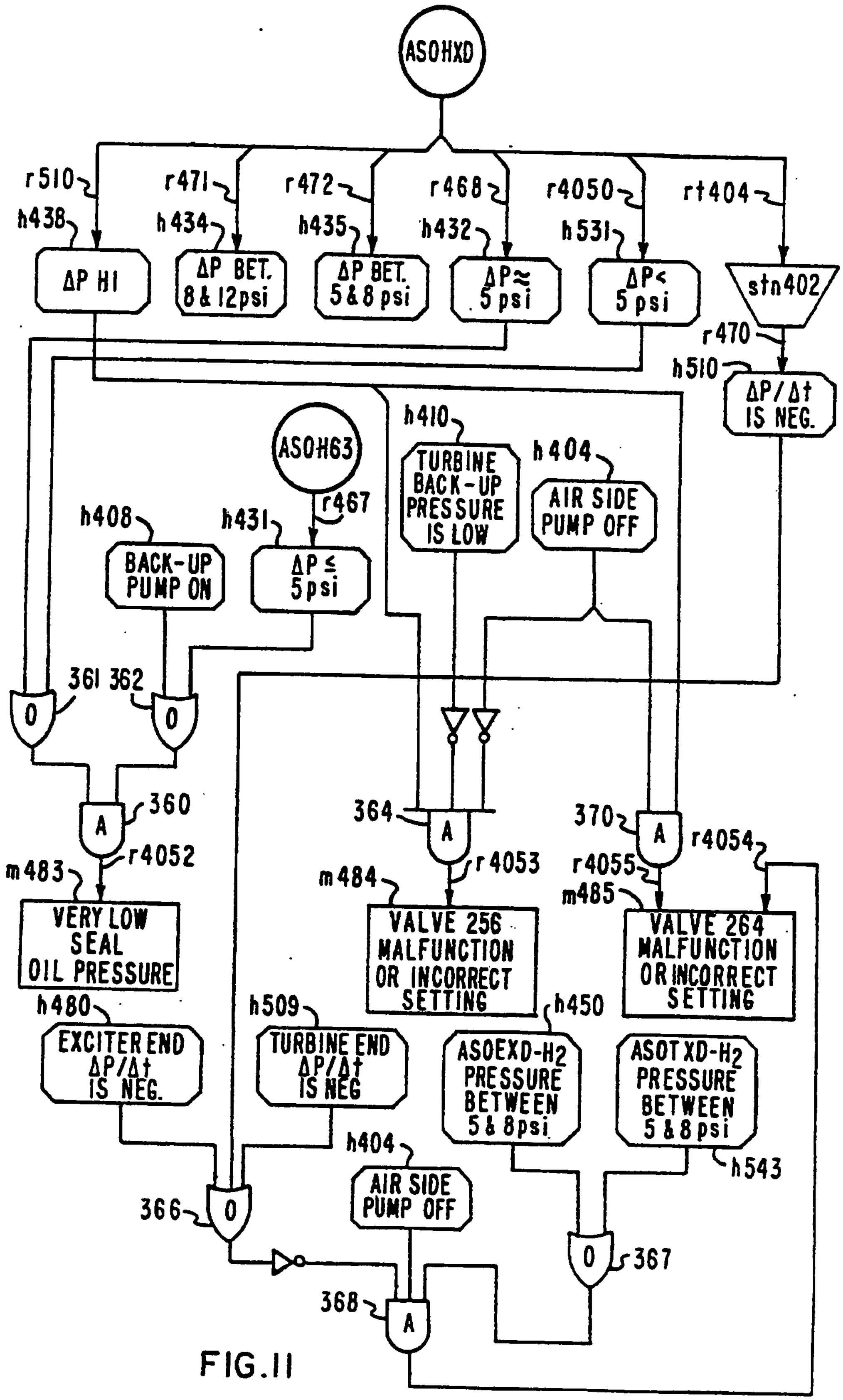
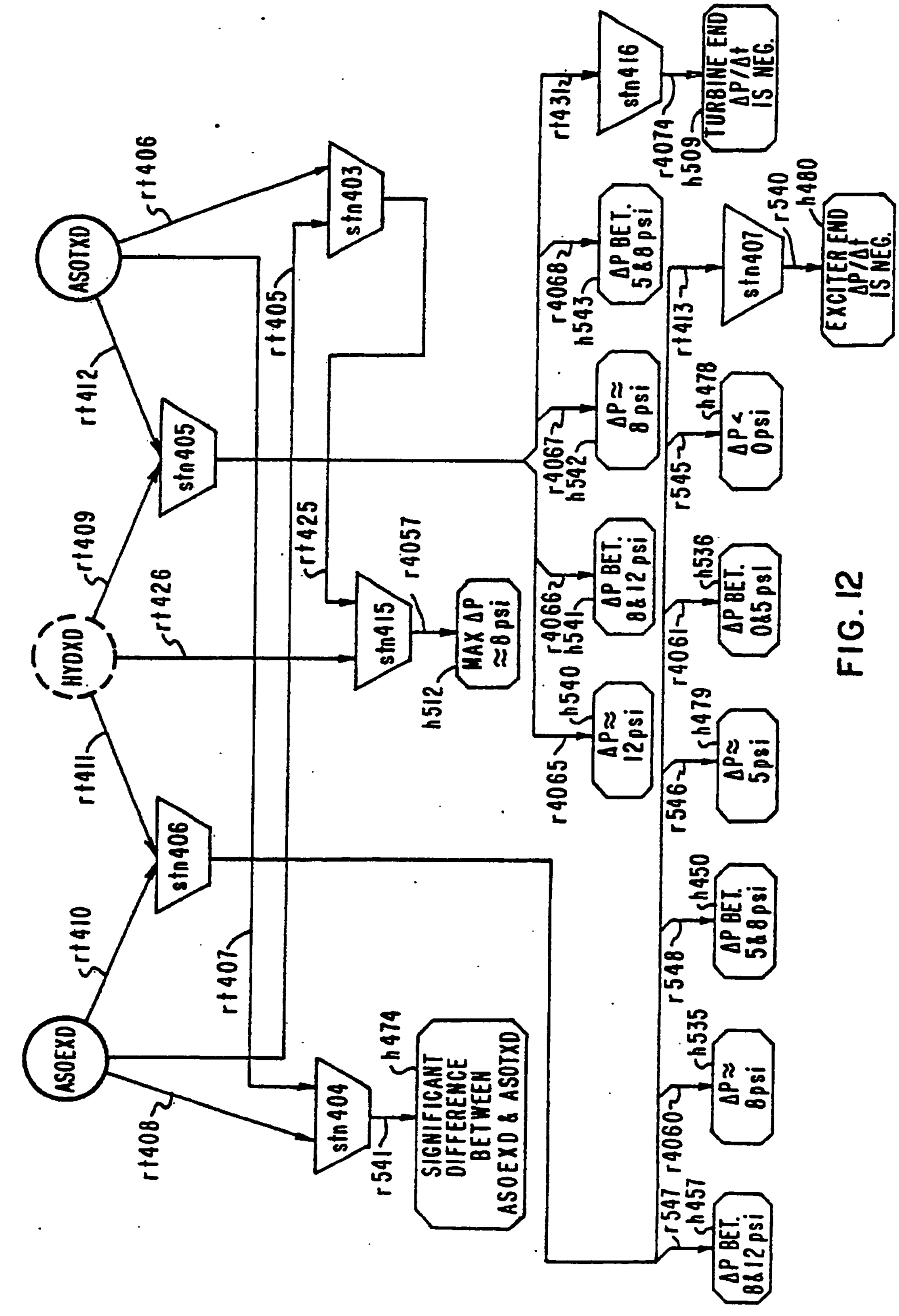

DTT71
r422
h414
LEVEL HI
351
A
r533
h527
LEVEL HI & OIL HOT
h484
H2 SIDE SEAL OIL IS HOT
357
r4046
m409
HI LEVEL ON TURBINE END DEFOAMING TANK DUE TO HOT SEAL OIL
358
r532
m454
HI LEVEL ON TURBINE END DEFOAMING TANK DUE TO OBSTRUCTED LINE
352
r4127
h570
BOTH SIDES ARE HI
354
r4045
m482
HI LEVEL ON BOTH DEFOAMING TANKS DUE TO HOT SEAL OIL
356
r539
m457
HI LEVEL ON EXCITER END DEFOAMING TANK DUE TO OBSTRUCTED LINE
h484
H2 SIDE SEAL OIL IS HOT
DTE71
r535
h472
LEVEL HI
350
r538
h526
LEVEL HI & OIL HOT
355
r4044
m456
HI LEVEL ON EXCITER END DEFOAMING TANK DUE TO HOT SEAL OIL

FIG.10



ASOHXD
r510
h438
ΔP HI
r471
h434
ΔP BET. 8 & 12psi
r472
h435
ΔP BET. 5 & 8 psi
r468
h432
ΔP≈ 5 psi
r4050
h531
ΔP< 5 psi
rt404
stn402
r470
h510
ΔP/Δt IS NEG.
ASOH63
r467
h431
ΔP ≤ 5psi
h408
BACK-UP PUMP ON
h410
TURBINE BACK-UP PRESSURE IS LOW
h404
AIR SIDE PUMP OFF
361
362
0
0
A
360
r4052
m483
VERY LOW SEAL OIL PRESSURE
364
A
r4053
m484
VALVE 256 MALFUNCTION OR INCORRECT SETTING
370
A
r4054
r4055
m485
VALVE 264 MALFUNCTION OR INCORRECT SETTING
h480
EXCITER END ΔP/Δt IS NEG.
h509
TURBINE END ΔP/Δt IS NEG
h450
ASOEXD-H2 PRESSURE BETWEEN 5 & 8psi
ASOTXD-H2 PRESSURE BETWEEN 5 & 8 psi
h543
h404
AIR SIDE PUMP OFF
366
0
0
367
368
A

FIG.11



ASOEXD
HYDXD
ASOTXD
rt410
rt411
rt409
rt412
rt406
rt408
rt407
rt426
rt405
rt425
stn406
stn405
stn403
stn404
stn415
r541
h474
SIGNIFICANT DIFFERENCE BETWEEN ASOEXD & ASOTXD
r4057
h512
MAX ΔP ≈8 psi
r4065
h540
ΔP≈ 12psi
r4066
h541
ΔP BET. 8&12 psi
r4067
h542
ΔP≈ 8 psi
r4068
h543
ΔP BET. 5&8 psi
rt431
stn416
r4074
h509
TURBINE END ΔP/Δt IS NEG.
r547
h457
ΔP BET. 8&12 psi
r4060
h535
ΔP≈ 8psi
r548
h450
ΔP BET. 5&8 psi
r546
h479
ΔP≈ 5psi
r4061
h536
ΔP BET. 0&5 psi
r545
h478
ΔP< 0psi
r413
stn407
r540
h480
EXCITER END ΔP/Δt IS NEG.

FIG. 12

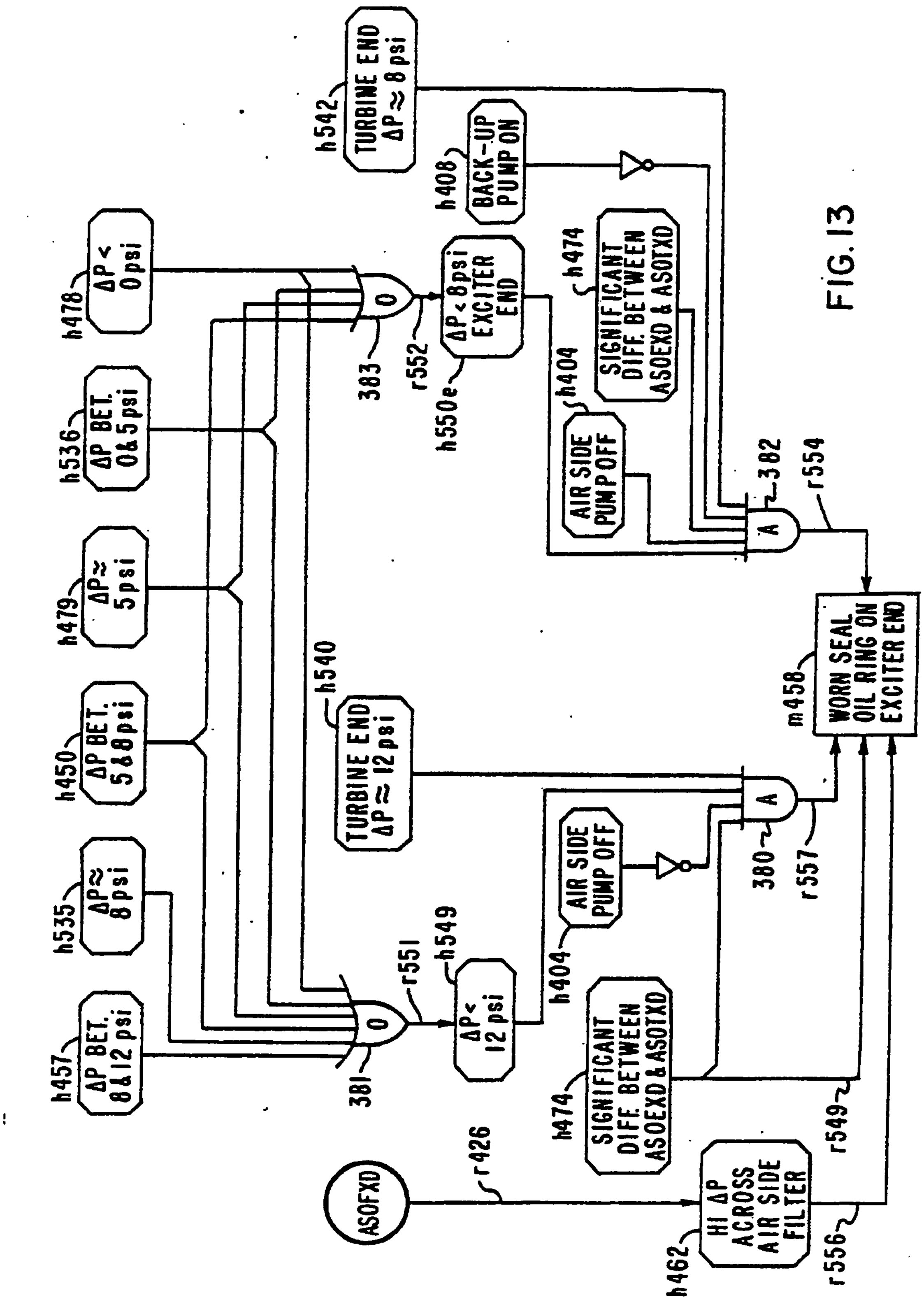

h542
TURBINE END ΔP ≈ 8 psi
h408
BACK-UP PUMP ON
h478
ΔP < 0 psi
383
r552
ΔP < 8 psi EXCITER END
h550e
h474
SIGNIFICANT DIFF. BETWEEN ASOEXD & ASOTXD
h404
AIR SIDE PUMP OFF
382
r554
A
O
h536
ΔP BET. 0 & 5 psi
h479
ΔP ≈ 5 psi
h450
ΔP BET. 5 & 8 psi
h540
TURBINE END ΔP ≈ 12 psi
m458
WORN SEAL OIL RING ON EXCITER END
h535
ΔP ≈ 8 psi
380
r557
h457
ΔP BET. 8 & 12 psi
381
r551
h549
ΔP < 12 psi
ASOFXD
r426
h462
HI ΔP ACROSS AIR SIDE FILTER
r549
r556

FIG. 13

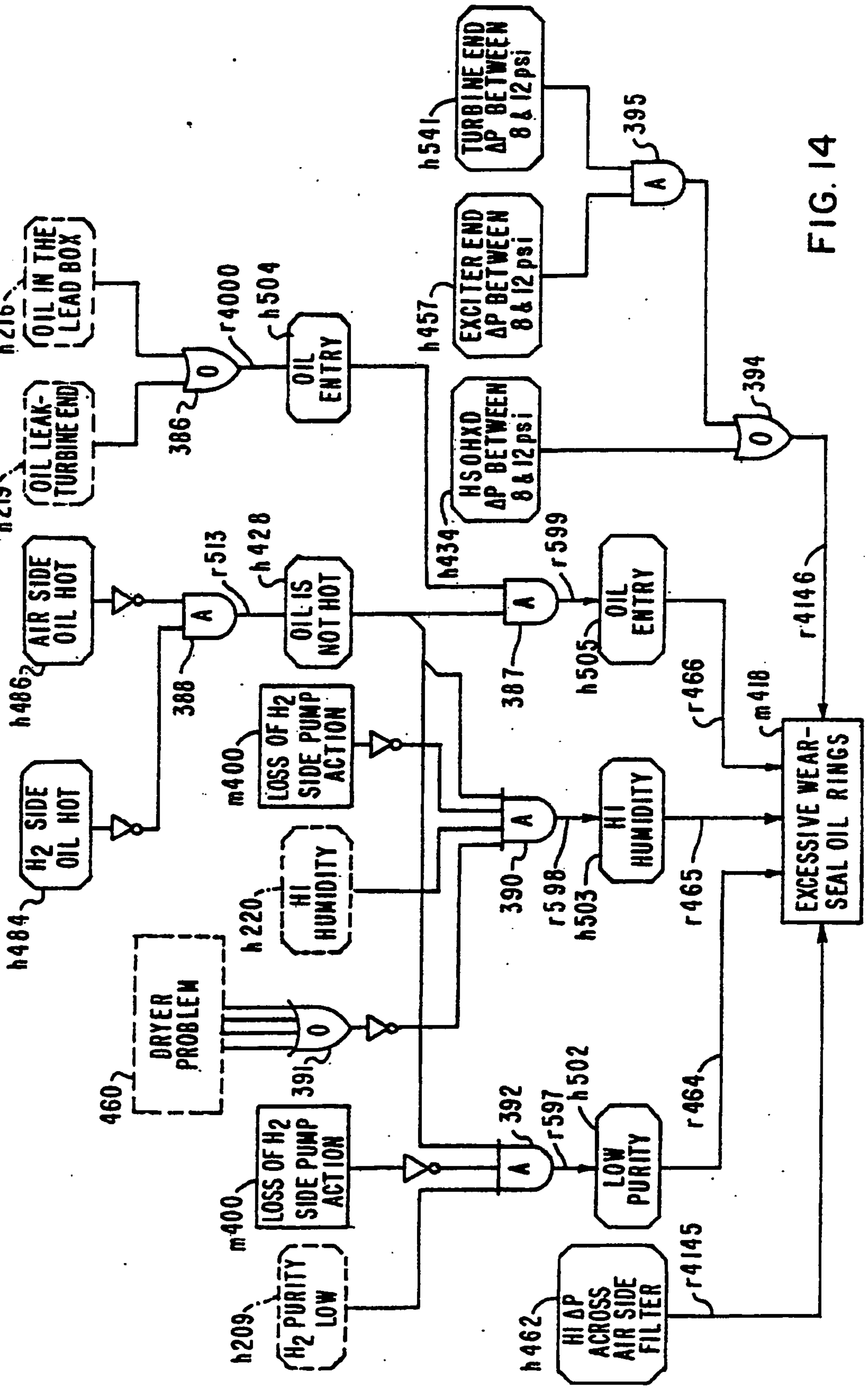

h484
H2 SIDE OIL HOT
h486
AIR SIDE OIL HOT
388
A
r513
h428
OIL IS NOT HOT
h219
OIL LEAK-TURBINE END
h216
OIL IN THE LEAD BOX
386
O
r4000
h504
OIL ENTRY
m400
LOSS OF H2 SIDE PUMP ACTION
h220
HI HUMIDITY
460
DRYER PROBLEM
391
O
390
A
r598
h503
HI HUMIDITY
387
A
r599
h505
OIL ENTRY
h434
HSOHXD ΔP BETWEEN 8 & 12 psi
h457
EXCITER END ΔP BETWEEN 8 & 12 psi
h541
TURBINE END ΔP BETWEEN 8 & 12 psi
395
A
394
O
r4146
r466
m418
EXCESSIVE WEAR-SEAL OIL RINGS
r465
r464
m400
LOSS OF H2 SIDE PUMP ACTION
392
A
r597
h502
LOW PURITY
h209
H2 PURITY LOW
h462
HI ΔP ACROSS AIR SIDE FILTER
r4145

FIG. 14

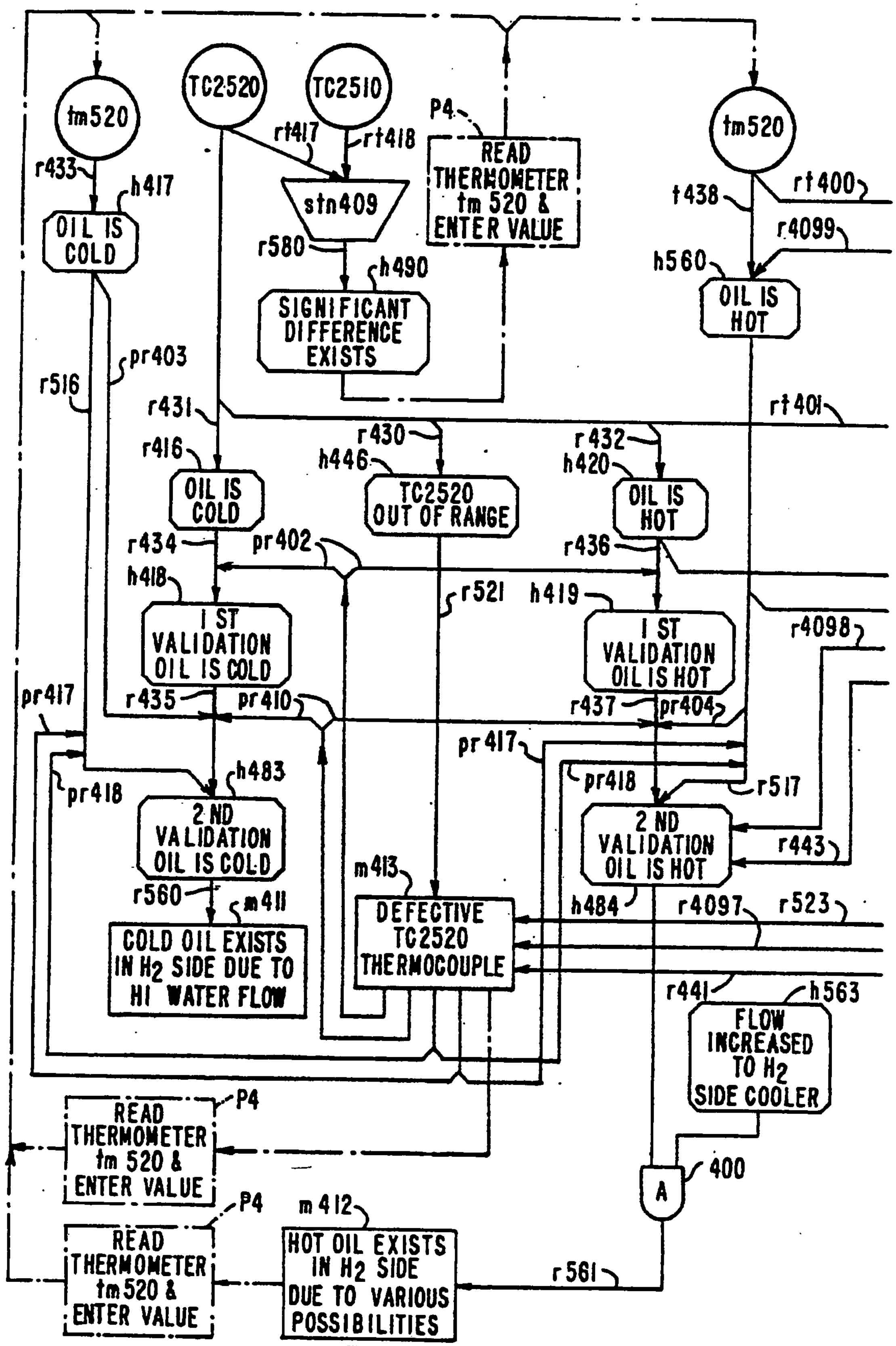

tm520
TC2520
TC2510
P4
READ THERMOMETER tm 520 & ENTER VALUE
tm520
r433
h417
OIL IS COLD
rt417
rt418
stn409
r580
h490
SIGNIFICANT DIFFERENCE EXISTS
t438
rt400
r4099
h560
OIL IS HOT
r516
pr403
r431
rt401
r416
OIL IS COLD
r430
h446
TC2520 OUT OF RANGE
r432
h420
OIL IS HOT
r434
pr402
r436
h418
I ST VALIDATION OIL IS COLD
r521
h419
I ST VALIDATION OIL IS HOT
r4098
pr417
r435
pr410
r437
pr404
pr417
pr418
r517
pr418
h483
2 ND VALIDATION OIL IS COLD
2 ND VALIDATION OIL IS HOT
r443
m413
r560
m411
COLD OIL EXISTS IN H2 SIDE DUE TO HI WATER FLOW
DEFECTIVE TC2520 THERMOCOUPLE
h484
r4097
r523
r441
h563
FLOW INCREASED TO H2 SIDE COOLER
P4
READ THERMOMETER tm 520 & ENTER VALUE
400
A
P4
m 412
READ THERMOMETER tm520 & ENTER VALUE
HOT OIL EXISTS IN H2 SIDE DUE TO VARIOUS POSSIBILITIES
r561

FIG. 15A

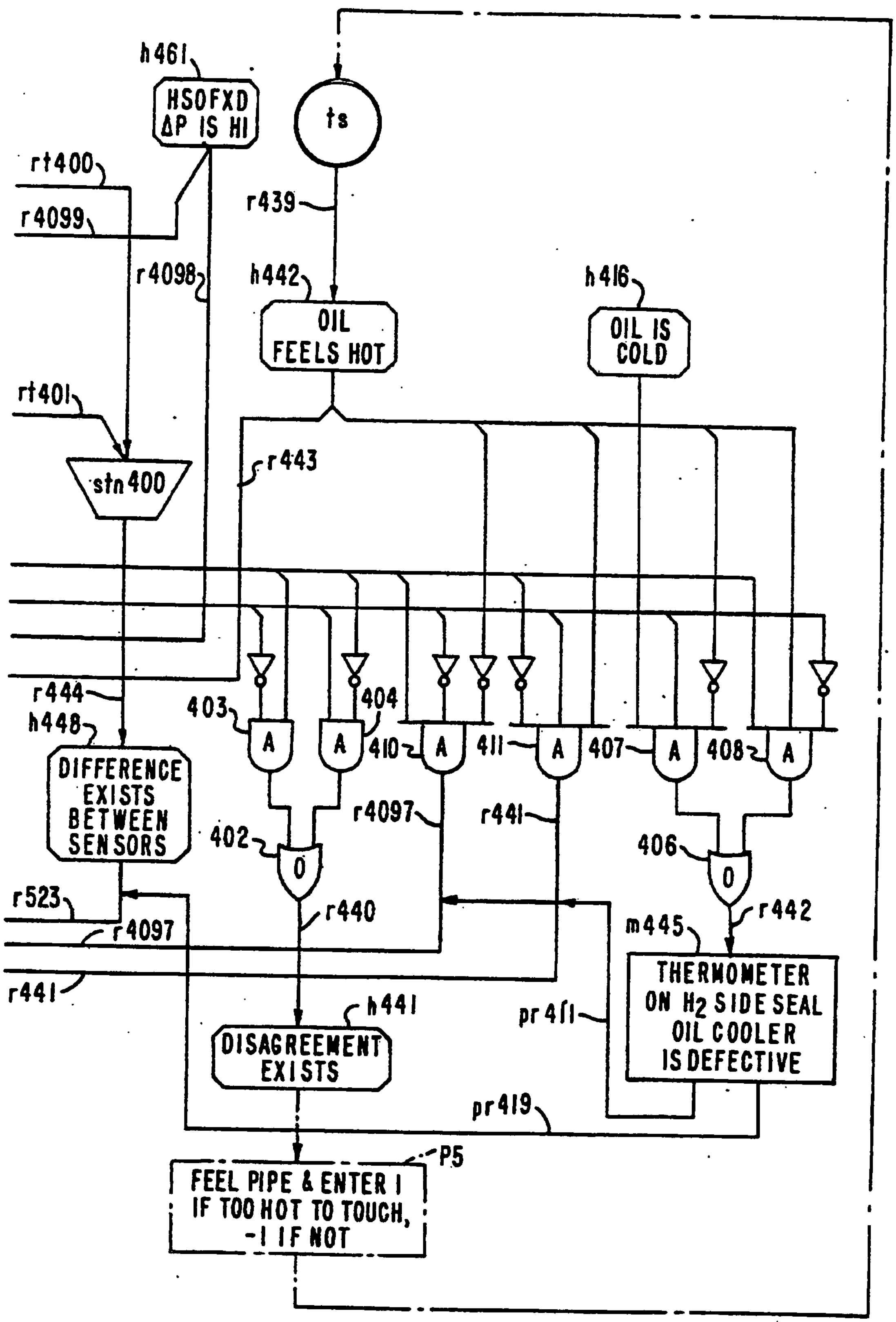

h461
HSOFXD ΔP IS HI
ts
rt400
r4099
r439
r4098
h442
OIL FEELS HOT
h416
OIL IS COLD
rt401
stn400
r443
r444
h448
DIFFERENCE EXISTS BETWEEN SENSORS
403
404
410
411
407
408
A
402
0
r4097
r441
406
r523
r440
r442
m445
THERMOMETER ON H2 SIDE SEAL OIL COOLER IS DEFECTIVE
h441
DISAGREEMENT EXISTS
pr411
pr419
P5
FEEL PIPE & ENTER 1 IF TOO HOT TO TOUCH, -1 IF NOT

FIG. 15B

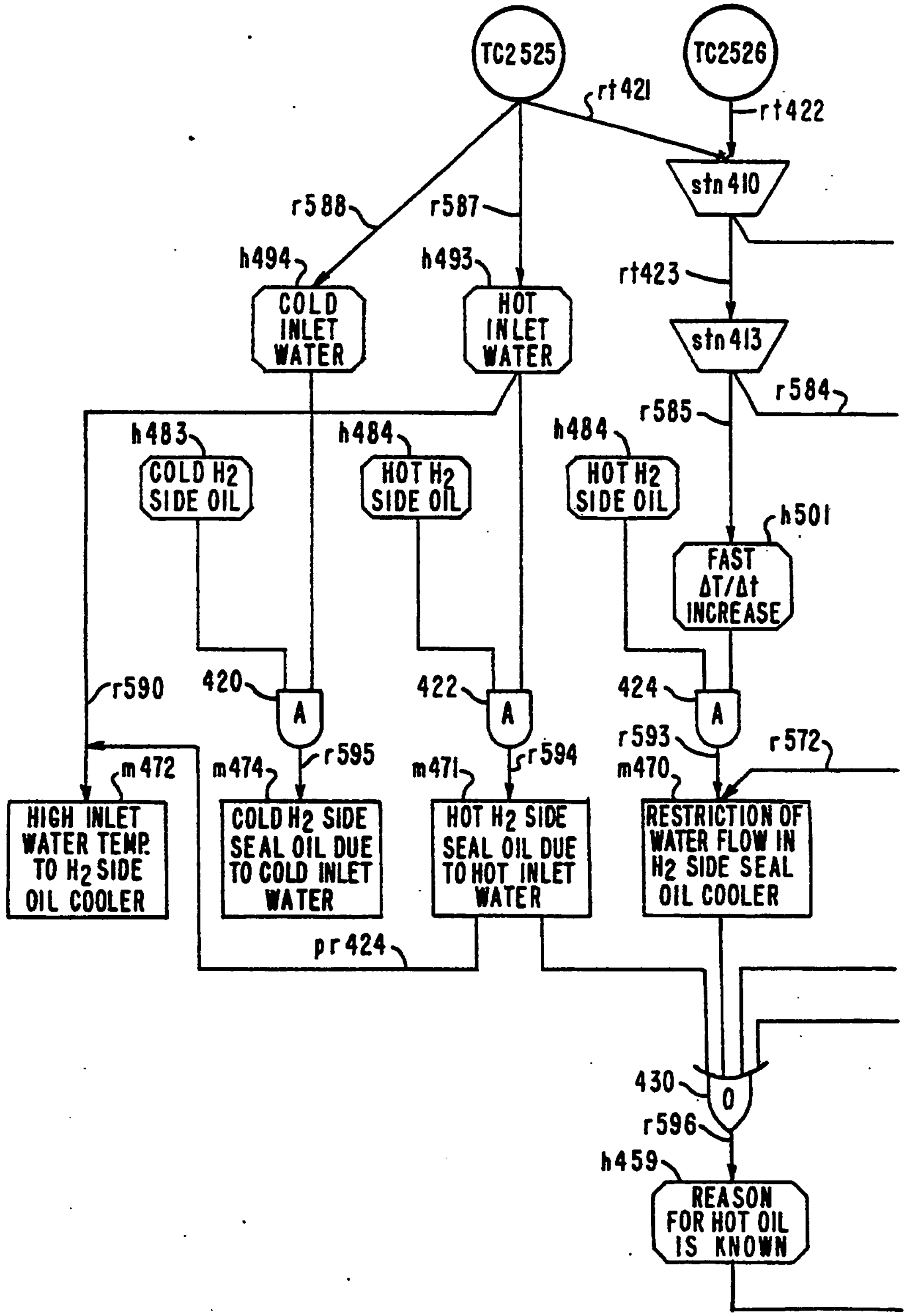
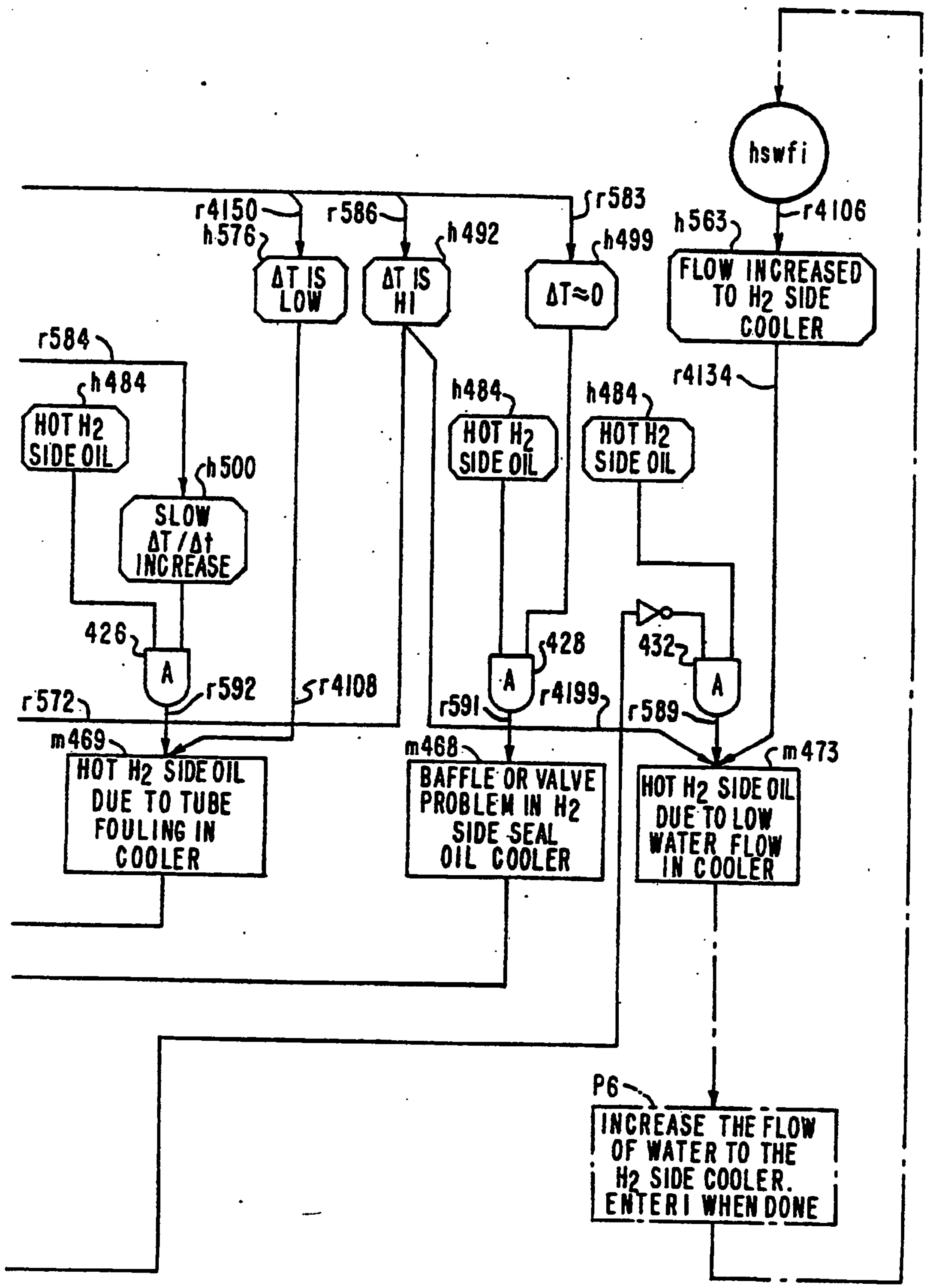

TC2525
TC2526
rt421
rt422
stn410
r588
r587
rt423
h494
h493
COLD INLET WATER
HOT INLET WATER
stn413
r584
r585
h483
h484
h484
COLD H2 SIDE OIL
HOT H2 SIDE OIL
HOT H2 SIDE OIL
h501
FAST ΔT/Δt INCREASE
r590
420
A
422
A
424
A
r595
r594
r593
r572
m472
m474
m471
m470
HIGH INLET WATER TEMP. TO H2 SIDE OIL COOLER
COLD H2 SIDE SEAL OIL DUE TO COLD INLET WATER
HOT H2 SIDE SEAL OIL DUE TO HOT INLET WATER
RESTRICTION OF WATER FLOW IN H2 SIDE SEAL OIL COOLER
pr424
430
O
r596
h459
REASON FOR HOT OIL IS KNOWN

FIG. 16A



hswfi
r4150
h576
r586
h492
r583
h499
h563
r4106
ΔT IS LOW
ΔT IS HI
ΔT≈0
FLOW INCREASED TO H2 SIDE COOLER
r584
h484
HOT H2 SIDE OIL
h500
SLOW ΔT/Δt INCREASE
r4134
h484
HOT H2 SIDE OIL
h484
HOT H2 SIDE OIL
426
A
r592
r4108
428
A
432
A
r572
r591
r4199
r589
m469
HOT H2 SIDE OIL DUE TO TUBE FOULING IN COOLER
m468
BAFFLE OR VALVE PROBLEM IN H2 SIDE SEAL OIL COOLER
m473
HOT H2 SIDE OIL DUE TO LOW WATER FLOW IN COOLER
P6
INCREASE THE FLOW OF WATER TO THE H2 SIDE COOLER. ENTER I WHEN DONE

FIG. 16B

FIG. 17A

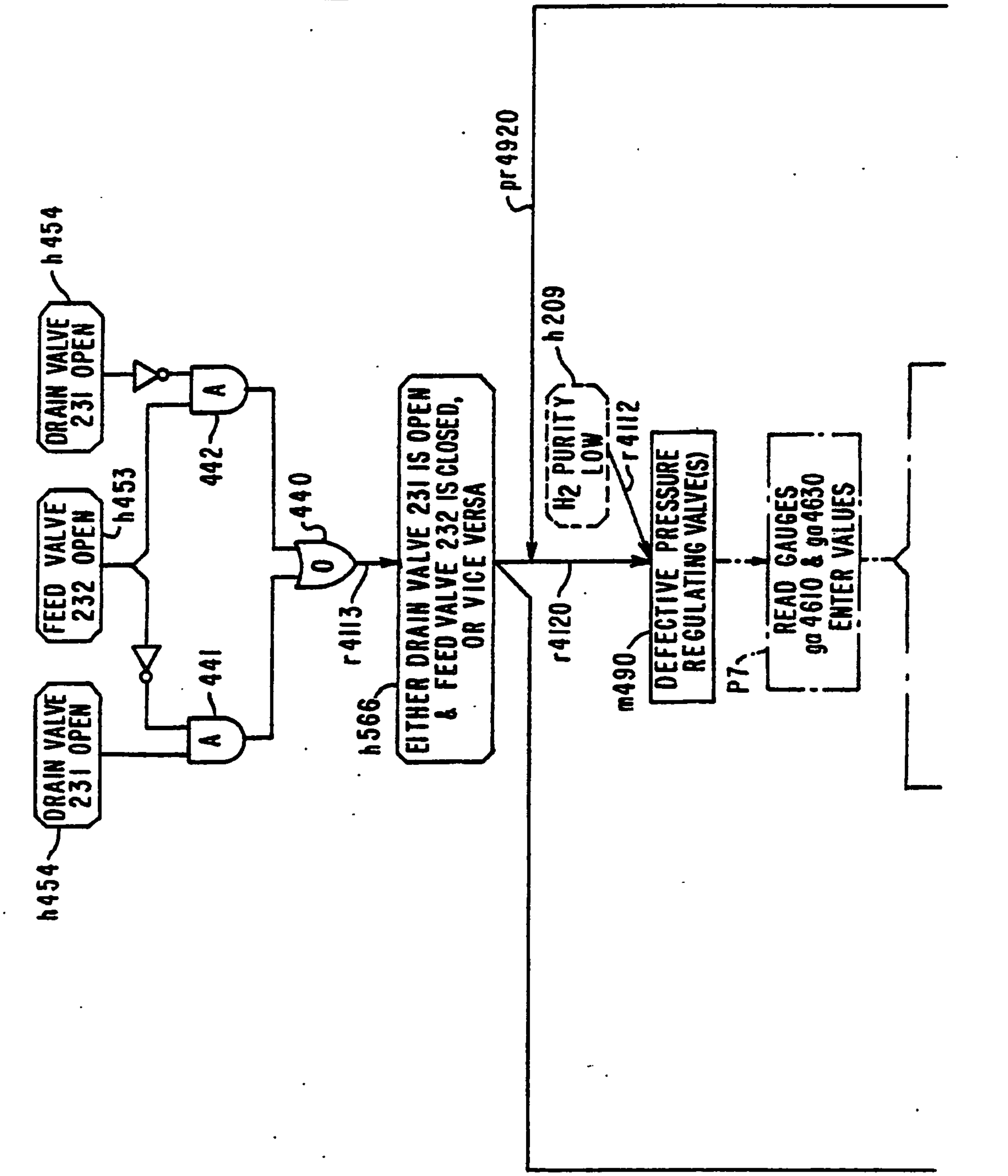
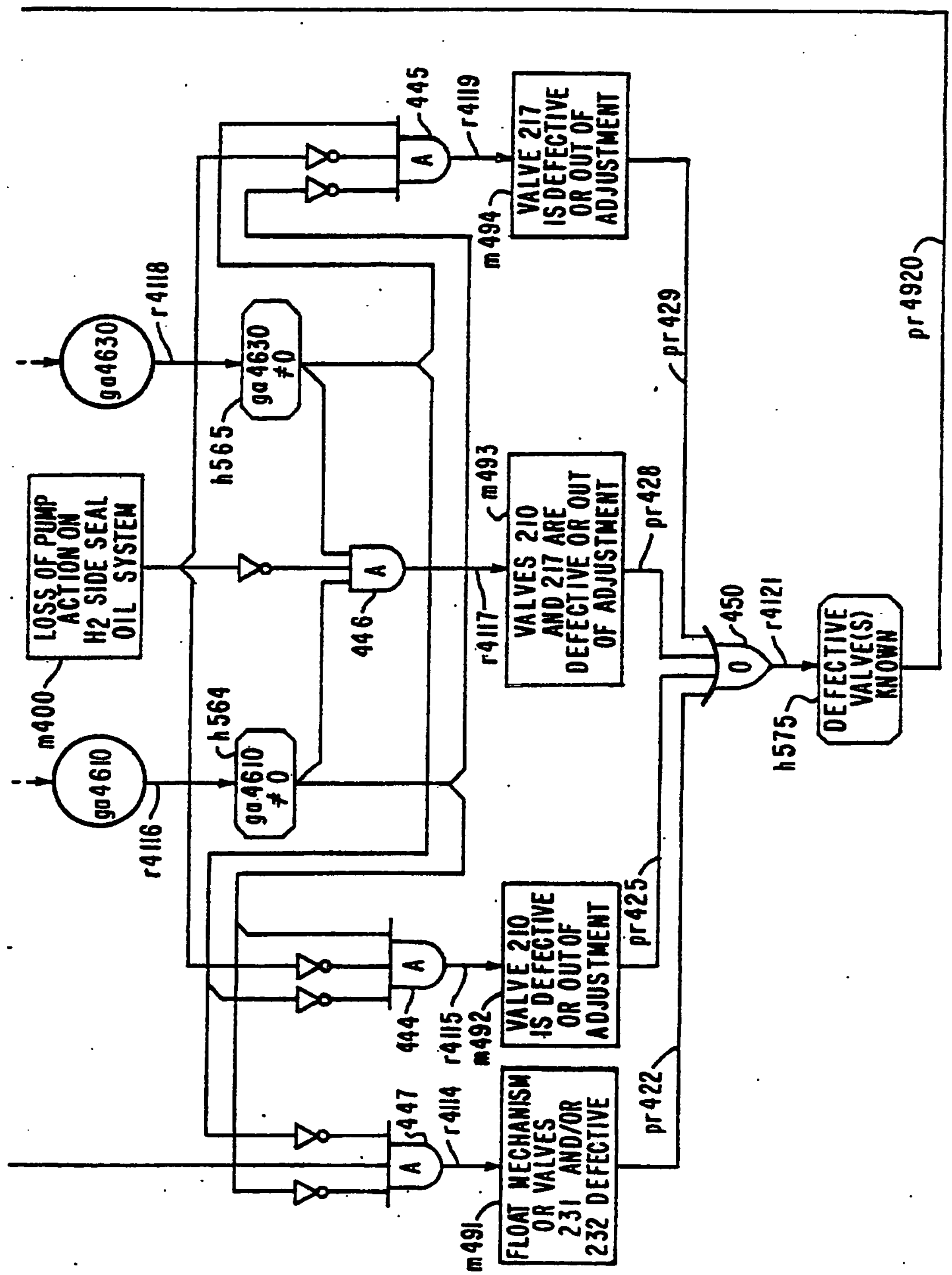

h454
DRAIN VALVE 231 OPEN
h453
FEED VALVE 232 OPEN
h454
DRAIN VALVE 231 OPEN
441
A
442
A
440
O
r4113
h566
EITHER DRAIN VALVE 231 IS OPEN & FEED VALVE 232 IS CLOSED, OR VICE VERSA
pr4920
h209
H2 PURITY LOW
r4112
r4120
m490
DEFECTIVE PRESSURE REGULATING VALVE(S)
P7
READ GAUGES ga4610 & ga4630 ENTER VALUES

FIG.17B


LOSS OF PUMP ACTION ON H2 SIDE SEAL OIL SYSTEM
m400
ga4610
ga4630
r4116
r4118
h564
h565
ga4610 ≠0
ga4630 ≠0
A
O
444
445
446
447
450
r4114
r4115
r4117
r4119
r4121
m491
m492
m493
m494
FLOAT MECHANISM OR VALVES 231 AND/OR 232 DEFECTIVE
VALVE 210 IS DEFECTIVE OR OUT OF ADJUSTMENT
VALVES 210 AND 217 ARE DEFECTIVE OR OUT OF ADJUSTMENT
VALVE 217 IS DEFECTIVE OR OUT OF ADJUSTMENT
pr422
pr425
pr428
pr429
pr4920
h575
DEFECTIVE VALVE(S) KNOWN